Contents

About the authors viii
Preface ix
Acknowledgements x

Year 1

Section 1: Diversity of matter

Unit 1: Introduction to integrated science

Nature of science and technology 2
The concept of integrated science 2
Branches of science 3
Careers in science and technology 4
The scientific method 4
Safety precautions in the laboratory 5

Unit 2: Measurement

Units of measurement 7
Using scientific measuring instruments 9

Unit 3: Diversity of living and non-living things

Living and non-living things 9
Classifying things 10
Branches of biology 19
Branches of chemistry 19
Biological classification 20
Viruses 21
Bacteria 24
Protoctists and fungi 25
Plants 31
Animals 31
Ecology 33
Ecosystems 35
Habitats 38
Adaptations and extremophiles 40
Biodiversity 41
Conservation and sustainable use of biodiversity 42

Unit 4: Particulate nature of matter

Concentration of solutions 49

Unit 5: Cells and cell division

Structure and functions of the cell 49
Plant and animal cells 51
Levels of organisation of cells in living organisms 53
Cell division 54

Unit 6: Rocks

Rocks and their characteristics 58
Weathering of rocks 58
Soil 59

Section 2: Cycles

Unit 1: Air movement

Land and sea breezes 62
Types of air mass – their movement and effects 62
Precautions against the effects of severe storms 63
Air masses and pollutants 64

Unit 2: Nitrogen cycle

The nitrogen cycle 67
Importance of the nitrogen cycle 68

Section 3: Systems

Unit 1: The skeletal system

The mammalian skeleton 70
The axial skeleton 70
The appendicular skeleton 71
Joints 73
Skeletal disorders 73
Friction in mammals 74

Unit 2: Reproduction and growth in plants

Structure of the flower 76

Pollination 79
Fertilisation 80
Fruits 81
Seed structure 83
Dispersal of fruits and seeds 85
Seed germination 87
Asexual reproduction (vegetative propagation) 88

Unit 3: Respiratory system 94

Respiration 94
Structure and function of the respiratory system of mammals 97
Gas exchange in the lungs 99
Problems and disorders associated with the respiratory system of humans 100
Exchange of respiratory gases in plants 101

Unit 4: Food and nutrition 103

Types of food substances 103
Balanced and unbalanced diets 109

Unit 5: Dentition, feeding and digestion in mammals 111

Structure, functions and types of teeth in mammals 111
Structure and functions of the digestive system of mammals 115
Digestion in mammals 119
Disorders and diseases of the human digestive system 120
The liver 121

Unit 6: Transport – diffusion, osmosis and plasmolysis 124

Movement of substances in and out of cells 124
Transport in flowering plants – xylem and phloem 128

Section 4: Energy

Unit 1: Forms of energy and energy transformation 132

Forms of energy and energy transformation 132
Conservation of energy and efficiency of energy conversion 134

Unit 2: Solar energy 136

Uses of solar energy 136
Generation of electricity from solar panel/ solar cells 136
Solar heaters
Solar drier
Applications of solar energy

Unit 3: Photosynthesis

Photosynthesis in flowering plants

Unit 4: Electronics

Components in d.c and a.c. electronic circuits
Behaviour of components in d.c. and a.c. electronic circuits

Section 5: Interactions of matter

Unit 1: Ecosystems

Fundamental ecological concepts
Ecological factors
Types of ecosystem
Interrelationships in an ecosystem

Unit 2: Atmosphere and climate change

The atmosphere
Human activities and their effects on the atmosphere
Atmospheric pollution
Greenhouse effect, global warming and climate change
Depletion of the ozone layer and its effects
Acid rain and its effects

Unit 3: Tectonic movements

The layers of the Earth
Plate tectonics
Land formations and submerging lands

Unit 4: Infections and diseases

Diseases
Modes of transmission, syn
diseases

Year 2

Section 1: Diversi

Unit 1: Acids, base

Sources of acids, ba

Bronsted-Lowry definition of acids and bases – proton transfer 188
Preparation of salts 192
Acid–base indicators, the pH scale and universal indicator 196
Unit 2: Soil conservation 201
Principles of soil and water conservation 201
Soil fertility and productivity 202
Maintenance of soil fertility 203
Fertilisers 204
Compost 206
Depletion of soil resources 207
Soil erosion 208
Unit 3: Water 212
The properties of water 213
The nature of the water molecule 215
Hardness of water 216
Softening hard water 217
Purification of water – the treatment of water for public consumption 219
Uses of water 221

Section 2: Cycles

Unit 1: Water movement 223
Tides 223
Effects of tidal waves 224
Unit 2: The hydrological cycle 226
Sources of water 226
The water cycle and plants and animals 228
Water contamination and related diseases 230
Conservation of water 230

Section 3: Systems

Unit 1: The excretory system 234
What is excretion? 234
Excretory organs 235
Disorders of the urinary system in humans 237
Excretion in flowering plants 239
Unit 2: The reproductive system and growth in mammals 240
Structure and functions of the mammalian reproductive system 242
Male and female circumcision
Fertilisation and development of the zygote and birth in mammals 243
Birth in mammals 247
Reproductive hormones 248
Parental care in humans 248
Disadvantages of teenage pregnancy and parenthood 250
Some problems associated with reproduction in humans 250
Sexually transmitted diseases (STDs) 253
Stages of growth and development in humans 253
Early parenthood 257
Family planning 258
The menopause and effects of late delivery on women 259
Unit 3: The circulatory system 261
Transport in mammals 261
Composition and functions of blood and lymph 264
Disorders of the blood and circulatory system 266

Section 4: Energy

Unit 1: Electrical energy 268
Sources of static electricity 268
Sources of electric current 269
Electric circuits 270
Electrical power 273
Electric power generation 273
Power transformation and transmission 274
Household wiring 275
Unit 2: Electronics 279
Amplifier circuits 279
Project 282
Unit 3: Sound 283
Sources of sound 283
The speed of sound 53
The nature of sou
Musical notes and no
The human ear

Section 5: Interactions o

Unit 1: Magnetism
Magnetic and non-magnetic materials
Magnets

Uses of magnets 293
Magnetic fields 295
The Earth as a magnet 297
Magnetisation 298

Unit 2: Force and motion
Forces 300
Archimedes' principle 300
Distance, displacement, speed, velocity, acceleration and momentum 302
Newton's laws of motion 303
Centre of gravity 304
Moment of a force 306
Pressure 308

Unit 3: Safety in the community 308
Appliances used in the home 312
Precautions against accidents in the home 312
First Aid 313
Hazardous substances and their effects 314
Dust 317
Fumes and fires 318
Managing fires 319
Corrosive substances 320
Electric shock 322
Food contamination and poisoning 323
Harmful radiation (X-rays) and poisonous chemicals 323
Safe storage of hazardous substances and safety or hazard symbols 324
Summary of simple safety measures 324
Common hazards in the community 324
Public health 325
326

Year 3

Section 1: Diversity of matter

335
336
s and non-metals 337
nd non-metals 339
ivantages 341

metals 344
rification of aluminium 344
purification of gold 346

Social and economic impact of aluminium and gold production on an economy 349

Unit 3: Rusting 350
Chemical properties of aluminium and iron 350
Process of rusting of iron – corrosion, oxidation and reduction 351

Section 2: Cycles

Unit 1: Life cycle of pests and parasites 356
Types of pests and parasites of plants 356
Types of pests and parasites of farm animals 358
Pests and parasites of humans and their diseases 359

Unit 2: Crop production 366
General principles of crop production 367
Production of crops 376

Section 3: Systems

Unit 1: Nervous system 381
The structure and functions of the nervous system 381
Damage to the brain and spinal cord 383
Voluntary and involuntary actions 384
The endocrine system 386

Section 4: Energy

Unit 1: Light energy 389
Reflection of light 389
Formation of images 390
Refraction of light 393
Lenses 394
The human eye 395
Dispersion of light 397
Primary colours of light 399
Electromagnetic spectrum 399

Unit 2: Heat energy 402
The nature of heat 402
Measurement of heat 403
Transfer of heat 405
Temperature 407
Thermometers 408
Expansion due to heat 410
Expansion and contraction of liquids 412
Change in state of matter 412
Sublimation 416

CamScanner

Unit 3: Electronics 418
Transistors 418
Transistor circuits arranged as logic gates 418

Section 5: Interaction of matter

Unit 1: Variation, inheritance and evolution 422
Chromosomes and genes 422
Variation 423
Inheritance in organisms 425
Sex determination in humans 428
Blood groups 429
Sickle-cell anaemia 431
Theories of evolution 433
Evidence for evolution 434

Year 4

Section 1: Diversity of matter

Unit 1: Organic and inorganic compounds 440
Comparing organic and inorganic compounds 440
Organic compounds 442
Neutralisation and esterification 450
Petrochemicals 451

Section 2: Cycles

Unit 1: General principles of farm animal production 454
Main activities involved in animal production 455
Production of ruminants 458
Disease, pests and parasites 466
Production of non-ruminants 469

Section 4: Energy

Unit 1: Nuclear energy 487
Radioactivity 487
Nature and uses of radioisotopes 488
Nuclear energy and its uses 489
Protection from the effects of radioactivity 490
Disposal of nuclear waste 490

Unit 2: Electronics 492
Combination of transistors 492

Section 5: Interactions of matter

Unit 1: Work and machines 496
Work, energy and power 496
Simple machines 498
Friction 500

Unit 2: Endogenous technology 503
Science and technology 503
Science, technology and the development of society 504
Endogenous technology 506
Small-scale industries 506
Scientific principles involved in operation of some industries 511

Unit 3: Biotechnology 514
Biotechnology and its application 514
Industries based on biotechnology 514
Genetic engineering 516
Tissue culture 517

Revision questions 519

Answers to self check questions 527

Appendices

Appendix I SI units 529
Appendix II Size scale 529
Appendix III Periodic table of the elements 530
Appendix IV WAEC adapted IUPAC nomenclature for some inorganic substances 531
Appendix V Hazard/safety symbols 532
Appendix VI Common sources of food classes 533

Index 53

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Preface

Integrated Science for Senior High Schools has been written for students in the senior high classes.

The book has undergone a thorough revision in light of the 2007 curriculum reform and thus, this fourth edition provides full coverage of the new integrated science four-year national syllabus.

Any other reader will find this book a useful source of information on a wide range of basic scientific and technological topics.

The important features of the book are as follows:

- Syllabus topics from Biology, Chemistry, Physics, Agricultural Science, basic Information and Communication Technology have been adequately treated. Thus students as well as teachers will feel secure in using the book.
- Each unit begins with a list of learning objectives so that the student knows what goals are expected to be achieved by careful study of the chapter.
- The language level and depth in the text reflect the year group for which the text is written. This facilitates easy reading and understanding.
- The text is comprehensively and attractively illustrated with photographs and large, simple, clear and fully labelled diagrams to aid quick understanding and arouse interest.
- The salient ideas are either boxed or bulleted. Warnings are also boxed with the appropriate safety symbols.
- The book is activity oriented. This will aid better teaching and learning as well as application in daily life. Each of the large number of interesting and thought-provoking activities has a full list of clear and concise instructions. Relevant questions have been included.
- Each unit ends with a set of multiple-choice and essay-type questions entitled *Self check*. This is to enable the student to check his or her understanding of the text.
- At the end of the book there are a large number of revision questions, both objective and essay type. The questions cover the full range of specific objectives of the syllabus and are useful in preparing for tests and examinations.
- Answers to multiple-choice (objective) and numerical problems in the *Self check* sections are provided at the end of the book.

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Year 1

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1 Introduction to integrated science

Learning objectives

After studying this unit, you should be able to:

1 explain that there are various branches of science which are interrelated and relevant to the world of life
2 apply the scientific method to arrive at scientific solutions to everyday problems
3 follow basic safety precautions in the laboratory.

Background information

Ever since people appeared on Earth about 250,000 years ago, they have tried to improve their lives. Primitive people were hunters and gatherers. Later they became farmers, cultivating plants and rearing animals for their use. There were always problems to be solved, but it was not until people began to think logically and record information that real scientific progress began. Some of the earliest civilisations to think scientifically were the Egyptians and Greeks. From that time, science has developed into a unique way of solving problems.

Science uses methods involving logical investigation, experimentation and questioning that lead to reliable knowledge. The knowledge gained is stored and can be used to help further investigation and understanding.

Nations that can afford to spend large sums of money on scientific experimentation and the gathering of knowledge (data) advance the health and comfort of their people. Such nations become more efficient and successful and are able to anticipate and effectively cope with new problems.

Science has developed over the centuries into a number of interconnecting specialised branches. Simply put, science can be broken down into a number of branches, which are connected together, and help us to better understand the usefulness of science in the world of today and the future.

Nature of science and technology

Science can be defined in a number of ways, for example: 'Science is the process by which people accumulate knowledge and skills in which they can place a high, and often measurable, degree of confidence.'

Science is a continuous process of investigation and experimentation in order to widen people's understanding of the natural world. It involves the gathering and recording of knowledge to find answers to the questions and challenges that life poses every day. There are many methods of collecting information and forming ideas, but methods used by scientists must be systematic and reliable. These methods are often referred to as the **scientific method**.

Many skills are involved in the scientific method. It is an important goal of this book, and your work in science, that you acquire some, if not all, of these skills. With the aid of scientific skills and methods, men and women can achieve great things – the increase of food production, improvement of medical care, provision of better shelter, improvement of communication, designing better instruments, machines and many more.

The work of the scientist is far-reaching in every aspect of life. A lot of information about science can be found through the media (radio, TV and newspapers), and by reading scientific journals, magazines and books. These sources will show you how science has been involved in aspects of everyday life around you.

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For example, deciding which metals should be used to build suspension bridges, such as the Adomi Bridge at Atimpoku or Beposo; a scientific knowledge of how drugs work will help to improve their use and avoid their abuse; scientific knowledge has led to the extraction of gold, aluminium, silver and precious metals. Science is involved in soap and perfume manufacture to the development of complex electronics and rocket technology, and cures for malaria, cancer and other diseases.

Technology can be described as all the knowledge, products and scientific skills available to society being applied to improve life and to satisfy the needs of people. There is a close relationship between technology and science in particular, and with other disciplines. For example, historical accounts and awareness of the use of tallow, animal fat from goats, sheep or cattle, which give important information to soap chemists on one material in soap production. It leads to a search for other fats and oils of the same or similar chemical structure that can be used for the same purpose to give better quality and yield of soap. The other reactant, wood ash or dry plantain peel ash or dry cocoa pods ash, has been found to contain an alkali. This has led to the use of sodium hydroxide or potassium hydroxide, which are purer forms of the alkali, for soap making. In a simple way, science is 'know-why' while technology is 'know-how'.

Many technologists relate the discoveries that are made by pure scientists to the needs of society. As applied scientists, they apply and develop scientific ideas to produce new materials, tools and machines, medicines, improved forms of transport and communication, improvements in agriculture and biological systems, and in many other fields.

However, technology should not only be thought of as the application of the sciences. In fact, in history many technologies were in use many years before the science underpinning them were known, e.g. the chemistry of soap making, the physics and chemistry of melting, and fabrication of metals and steam engines. Our study of technology should involve the ability to:

- read and write about technological practices (literacy)
- be aware of and recognise technological developments
- use scientific and technological knowledge to solve some of the problems in our lives.

In the end, the practice of technology should make learners capable of developing new technologies to solve problems associated with life. To this end, the use of the sciences helps and encourages us to apply technologies in a humane and responsible manner to protect our environment and ourselves.

The concept of integrated science

Importance and interrelationships

There are many good reasons for studying integrated science, including:

- Science educates us. It tells us interesting and important things about ourselves and the world in which we live.
- Science offers reliable knowledge that we can use as a basis to cure diseases, communicate across the world, make our homes more comfortable, produce more and better crops, and many other things.
- Science has solved and continues to solve some of the world's problems. However, this success should not lead people to think that science can solve all the problems of the world.

Even science has its limits and can also be destructive!

People should be confident and able to thrive in the modern world of technology. There should be opportunities for people to acquire knowledge of their bodies, the world around them and the systems that affect their lives and their environment. This will enable them to recognise and appreciate the diversity of matter in the world, the interactions between the matter in it and energy, the balance of the natural systems and cycles that sustain life on earth.

Integrated science will be learnt under these five unifying themes as one whole or holistic subject in each year of the course. The study is organised into sections and learning units in each year of the four year course. A section states the theme and the unit specifies the topic as an example of the theme. The themes cut across common ideas in the various science subjects, such as biology, chemistry, physics, agricultural science and earth science.

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Example:
Year 1
Section 1: Diversity of matter
Unit 2: Measurement

Branches of science

Science can be broadly grouped into two branches:

- pure science – obtaining knowledge from research
- applied science – using knowledge from pure science to solve problems in our daily lives.

Pure science can be grouped into three main branches. Each branch can be further subdivided into a series of sub-branches (Table 1.1).

Table 1.1 Branches and sub-branches of science

Main branch	Sub-branches
biology	botany, microbiology, zoology
chemistry	inorganic, organic, physical
physics	atomic, electricity and magnetism, heat, light, mechanics, sound, astronomy

The knowledge acquired in a pure science is often applied to other branches of science. For example, consider the use of pesticides in agriculture (Figure 1.1). In the real world knowledge and skills from six different fields of science, and even outside it are used to produce one item, the pesticide. The basic principles of physics (a pure science) are mainly used in the scientific study of astronomy (an applied science). In our study of integrated science at the Senior High School, this integrated approach of acquiring knowledge and skills will be adopted. Three main reasons can be given for adopting this approach:

- to enable students who specialise in non-science subjects to have basic knowledge in the sciences to function properly in the modern world
- the natural world, its scientific and technological products is a world of all the sciences not of one elective subject
- all round basic knowledge in science, i.e. integrated science is helpful and required as a foundation to the study of both non-science and science courses at higher education levels.

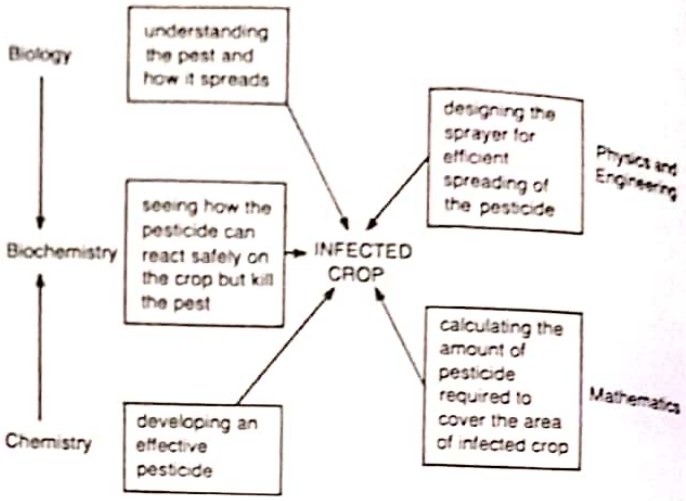


Fig 1.1 Knowledge from different branches of science combines to solve a problem.

Science and technology leads us to various activities and provide us with a great number of careers (Figure 1.2). Many of these link several branches of science. For example, a farmer will use chemistry in dealing with fertilisers, mathematics when preparing farm accounts, physics when using and maintaining machinery and equipment, and geology when working with the soil.

ACTIVITY 1 Interrelationships between the branches of science and technology

1 *Work in groups* to design and draw diagrams showing the interrelationship between the various branches of science and technology.

2 Discuss these diagrams with the class. Why do you think science specialists are needed?

Careers in science and technology

Many Ghanaians and others have distinguished themselves in many of the scientific fields of study mentioned. Some of these Ghanaians and their fields of study or work are described here.

Dr Letitia Obeng graduated in the biological sciences with an honours degree in zoology, obtained an MSc in parasitology, a PhD from work in freshwater sciences, and eventually specialised in water issues and the environment. Currently, she is President of the Ghana Academy of Arts and Sciences, the first female president in the academy's 39 years of existence.

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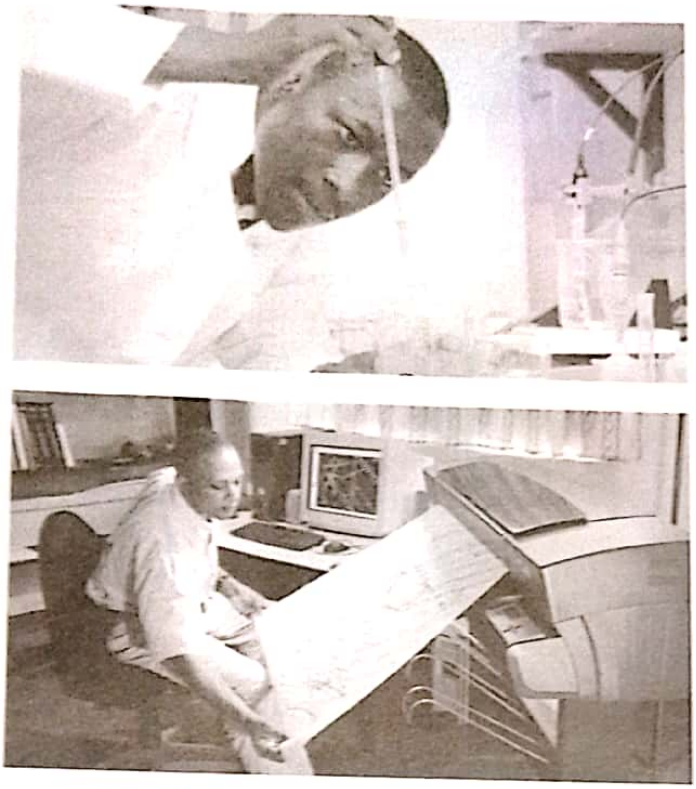


Fig 1.2 Careers in science and technology.

Prof. Ivan Addae-Mensah is Professor of chemistry and former Vice Chancellor of the University of Ghana. He obtained Bsc and Msc degrees in chemistry, and honorary doctorate degrees from New York University in 2002 and the University of Ghana in 2003, the Highest Honour of Soka University, Tokyo in 1998 and a PhD in organic chemistry from Churchill College, Cambridge University, England. In 2006 the state of Ghana awarded him the Companion of the Order of the Volta (COV) for his services to education and public affairs. He is currently Chairman of the National Petroleum Authority, and also a member of the National Council for Tertiary Education, the Council of the University of Mines and Technology at Tarwaka, and the Board of the United Nations University of Natural Resources in Africa.

Prof. Francis Kofi Ampenyin Allotey has extensive knowledge and experience in mathematics, physics and information technology. He earned a doctorate degree in mathematics and physics, and became the first Ghanaian full professor of mathematics. He was has been Chairman of the Ghana Atomic Energy Commission and also Chairman of the Council for Scientific and Industrial Research. He was first to introduce electron hole scattering resonance effects on soft X-ray spectroscopy. He was also the first person to introduce computer science education in Ghana, and served as a governor of the International Atomic Energy Agency (IAEA).

Dr Raphael Enerst Grail Amattow (1913–53) earned a doctorate degree in anthropology, philosophy and medicine and a master's degree in literature. He was a research scientist in cocoa swollen shoot disease, a medical doctor, anthropologist and poet. By 1950 he was described as Africa's greatest scientist within living memory.

Dr Isaiah M. Blankson earned a doctorate degree in aeronautics. In 2008 he works at the National Aeronautics and Space Agency (NASA). He has invented new types of jet engine, and designs rocket powered engines and high-speed supersonic planes.

Dr Gottlieb Kofi Noamesi earned a doctorate degree in biology. He has worked in the area of disease control and produced herbal medicines.

The scientific method

The scientific method is the way scientists work, and the important steps are:

1 **Identify the problem** – decide exactly what you want to do after careful observation.
2 **State the aim** – this is the reason for your investigation, e.g. 'to investigate the effect of area on pressure'.
3 **Formulate a hypothesis** – this is a statement which you will aim to prove (or disprove) by your investigation, e.g. 'pressure increases as area decreases'.
4 **Prepare and plan the investigation** – find out all you can about the problem; decide what to do and how to go about it.
5 **Experimentation** – carry out practical work by making observations and measurements.
6 **Data collection** – collect and record data.
7 **Analysis of data** – explain and draw inferences (deductions) from the experimental data and other sources in order to prove the hypothesis.
8 **Conclusion** – look at all the aspects of the investigation and make a brief statement on whether

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the hypothesis has been proved or disproved. If necessary, other useful things encountered and suggestions for further experiments can be included in the conclusion.

Any aspiring scientist must be curious. Any effort to understand how and why things happen, or how they could be improved, should involve the scientific method of investigation – solving problems and testing the truth of the answer.

Penicillin

Many great scientists made discoveries using the scientific method. In 1926 the British bacteriologist Alexander Fleming was working in a London hospital looking at the bacteria, *Staphylococcus*. He was examining plate cultures of *Staphylococcus* when one day he noticed an unexpected mass of fluffy mould growing in the cultures. After some time these masses became dark green in colour and were later identified as *Penicillium notatum*, similar to the mould that grows on orange peel. Five days after he noticed this unexpected growth of mould, Fleming discovered that it secreted a substance which was able to permeate the culture medium. Around the regions where the mould grew, a clear zone was found with no staphylococci. As the mould grew, so did the clear zone where no staphylococci could exist.

At that time, Fleming concluded that the mould (which he named *Penicillium*) could have produced a substance that was able to fight bacterial growth. This theory was not accepted, even though he conducted many more scientific experiments with careful controls in an attempt to prove it. At the beginning of the Second World War, Howard Florey attempted to find substances that might be capable of fighting the bacterial infections that developed in wounds and made it difficult or impossible for the wounds to heal. After reading about Fleming's work Florey conducted further experiments which led to the acceptance and development of **penicillin** as an **antibiotic** – a medicinal substance that kills bacteria or makes them inactive.

Scientific knowledge and understanding often take many years and many people to reach acceptable conclusions. Rarely is any scientific discovery achieved quickly, as the method itself demands repeated testing and experiments to ensure that the discovery was not a chance event. Fact has to be proven, and this may take many generations to achieve, with disappointment for scientists whose original idea was unused or rejected, only to be proved many years later through extended research.

Radioactivity

In 1896 Henri Becquerel was investigating the action of bright sunlight and uranium salts on a photographic plate. These plates were securely wrapped in black paper so that sunlight did not affect them. But when placed near the uranium compounds the plates became fogged, despite the fact that they were covered. Something must have got through the covering, and it was suggested that the uranium spontaneously emitted some rays, then known as Becquerel rays. The theory was modified through the further experiments of Roentgen and the Curies to explain the cause of the fogging. It was found that uranium gives off particles spontaneously by a process known as **radioactivity**. It was these radioactive particles that penetrated the covers of the plates. One experiment may lead to a very unexpected conclusion, as you have seen from the examples. The importance of research and repeated testing in science is therefore clear.

These are not typical examples of scientific method but more of accidents that can be interpreted by the scientifically trained mind. In order to test and verify their observations, both Fleming and Becquerel needed to use the scientific method. They tested their hypotheses by further experiments, checking and rechecking their results, until finally they could say that their original observations were correct.

Flotation

Archimedes is regarded as one of the great scientists of all times. He is considered to be the pioneer of experimental science because he was interested in carrying out experiments to explain and prove scientific theories. His law of flotation, called Archimedes' principle, explains why some bodies float in liquids. He is said to have made the discovery that led to the formulation of the law while he was in a bath. His king had asked him to find out if his new crown was pure gold or a mixture of gold and silver. When he stepped in the bath one day he noticed that the water overflowed the bath. He then concluded that a body immersed in water must displace a volume of water equal to the

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weight or mass of that body. He determined from this conclusion that the crown, although its weight agreed with that of the gold sent to the goldsmith, was greater in volume than the same weight of pure gold. It turned out that the goldsmith had kept part of the king's gold and was therefore punished!

We apply scientific concepts and principles in everyday life activities, such as cooking, walking and others.

Safety precautions in the laboratory

A school science laboratory is a place that students, technicians and teachers work. Items in a laboratory include equipment, instruments, storage furniture, chemicals and gas, water and electricity supply points. It is a place with many hazards and potentially dangerous materials gathered together in a small area, yet human activities have to be carried out there. The activities include preparations by teachers and technicians for experiments to be carried out by the teachers themselves and students.

Dangers and hazards may be natural – coming from all the items in the laboratory or created by people carrying out experiments. Students must develop an awareness of the dangers and hazards so as to prevent accidents that may occur. If the accidents occur, the effects or harm that they may cause to our bodies, health and the environment should be known, managed and minimised. Skills should be acquired to give confidence to students to apply safety precautions at all times.

There are many precautions that can guide safe work in the laboratory because of the numerous things that exist in the laboratory and activities carried out in it. Each person working in the laboratory should understand that everybody's safe conduct affects all the others. One careless act or omission can lead to accidents that may be fatal and destructive to many. The following guidelines are some of the precautions that should be noted or observed in working in the laboratory. Generally, the use of common sense – good judgement and experience from cause and effect situations in life – is a good guide.

- Wear a laboratory coat and shoes to protect your body and feet.
- Do not taste, drink or eat in the laboratory unless your teacher says it is safe.
- Wear protective goggles or use a protective shield to protect your eyes and body from hazards, such as dangerous splashes and explosions.
- When heating in a test tube, do not point the mouth of the tube towards yourself or another person. To avoid splashing liquid or cracking the test tube, swirl the liquid repeatedly and in and out of the hot part of the flame to spread the heat.
- When possible, heat inflammable substances in a water bath to minimise direct contact of the inflammable vapour with the fire source.
- Use a test tube holder, tongs or soft cloth to hold hot things where possible. Place very hot materials on a heat proof mat to avoid burning your hand or work surfaces.
- Follow instructions carefully and do not carry out any experiment without the knowledge of your teacher.
- Always add acid to water whilst stirring and not water to acid. This enables the heavier acid to fall to the bottom of the container and in the process mix well to spread any heat formed to avoid boiling.
- Do not work with broken glassware or sharp edged metals.
- Do not take fire to an inflammable substance or vice versa. If a small gas fire breaks out, try and turn off the gas, electricity and water. Small fires may be put out with a fire blanket before they become a big fire.
- Accidents and breakages must be reported to your teacher or technician.
- Any chemical spilled on the body must be rinsed well with plenty of water and then reported immediately to your teacher or technician.
- After carrying out an experiment, wash the apparatus, work surface and clean your hands before leaving the laboratory.
- Make sure you know about the basic safety and hazard signs (see Appendix V).

ACTIVITY 2 Safety precautions in the laboratory

1 Your teacher will carry out demonstrations on safety precautions in the use of laboratory equipment, chemicals and so on.

2 *Work in groups* to discuss why it is important to observe sensible safety preacutions in the laboratory.

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Self check

For questions 1 to 4, choose the letter that refers to the correct option.

1 What is the name of the scientist who first discovered penicillin?

A Becquerel
B Fleming
C Archimedes
D Lavoisier

2 A chemical container in a laboratory has the hazard sign pasted on it as shown in Figure 1.3.

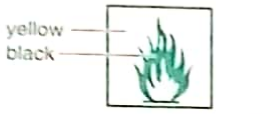


Fig 1.3

Care must be taken not to take the following near to the open container.

A water
B combustible material
C match fire
D magnet

3 When diluting an acid, such as tetraoxosulphates (VI), H_2SO_4 with water, the safe thing to do is to add the acid to the water and stir continuously. It is safe to do this because:

I H_2SO_4 is denser than water
II the heat generated is spread in the water
III water is lighter than H_2SO_4

A I and II
B II only
C II and III
D I, II and III

4 The following set of items are used when handling hot items in a laboratory:

A beaker, thermometer and heat mat
B test tube holder, heat mat and palette
C heat mat, Petri dish and mortar
D test tube holder, heat mat and tongs

5 Give a brief account of how a scientist works.

6 Give examples of careers that use aspects of each of the three sciences listed below.

a) biology
b) chemistry
c) physics.

7 Why are the following steps important in science?

a) analysis
b) controlled experiments
c) verification.

8 The following precautions are taken by students, teachers and laboratory technicians to make a laboratory safe. During a public demonstration explain briefly why each precaution is taken.

a) Do not work with a broken test tube.
b) When using a Bunsen burner strike the match first before turning the gas on not vice versa.
c) Do not smoke in the laboratory.
d) Do not eat in the laboratory.
e) Step down the mains voltage (240 V) before use in experiments with small light bulbs in the circuit.

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2 Measurement

Learning objectives

After studying this unit, you should be able to:

1 use SI units in all measurements accurately
2 use scientific measuring instruments accurately
3 measure density and relative density.

Background information

In order to bring order and uniformity into buying and selling goods, a system of measurement was needed. In the old days, the length of the King of England's foot was adopted as the foot, his arm's length as the yard and the first segment of his thumb as the inch, all now established as the **Imperial System** of measurement. Simon Stevis proposed a system of units based on the decimal system in the sixteenth century. However, in 1791, a decimal system of units, devised by a committee of the French Academy was adopted. The British Association for the Advancement of Science also selected the gram and centimetre as the basic units of mass and length. This system was called the **Metric System.**

Units of measurement

In 1960, a General Conference on Weights adopted a comprehensive system of units of measurement now called the **Système International** (International System), abbreviated to SI. In Ghana the Metrication Committee under the Standards Board was inaugurated in 1974 to change Ghana's system of measurement into the SI system.

SI units are described as standard units. A standard unit is a unit of measurement that is understood and accepted by people all over the world. Tables 1.2 and 1.3 describe modern standard units.

In Junior High School we studied the base units of measurement as well as derived units. The units are used to measure physical quantities, of which there are seven. Note that the physical quantities also have symbols just as units. They are used to express physical quantities to shorten writing of scientific information. For example, $l = 5$ m for length is five metres and $F = 2$ N for force is two newtons.

There are specific conventions for recording in SI units. The conventions include the following:

- Units should be written out in full using internationally agreed symbols.
- The letter 's' is never used to show a plural form, i.e. 5 kg and 5 cm (**not** 5 kgs or 5 cms) because s is the symbol for time in seconds.
- Capital letters are used in symbols only for certain units named after famous scientists, such as joule (J), watt (W) or newton (N).

Table 1.2 Base units in the SI system (base units are fundamental units from which all derived units can be obtained)

Quantity	Quantity symbol	SI unit	SI unit symbol
length	l	metre	m
mass	m	kilogram	kg
time	t	second	s
electric current	I	ampere	A
temperature	T	kelvin	K
luminous intensity	I_v	candela	cd
amount of substance	n	mole	mol

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Table 1.3 Derived units in the SI system (a derived unit is a combination of two or more base units)

Quantity (symbol)	SI unit	Symbol	Expressed in terms of SI units or derived units
force (F)	newton	N	1 N = 1 kg m s^{-2}
work and energy (E, U)	joule	J	1 J = 1 N m
power (P)	watt	W	1 W = 1 J s^{-1}
quantity of electricity (Q)	coulomb	C	1 C = 1 A s
electric potential (V)	volt	V	1 V = 1 W A^{-1}
electric resistance (R)	ohm	Ω	1 W = 1 V A^{-1}
volume (v)	cubic metre	m^3	m^3
density (ρ)	kilogram per cubic metre	kg m^{-3}	kg m^{-3}
frequency	hertz	Hz	s^{-1}

- When symbols are combined as a quotient, e.g. joules per second, they can be written as J/s or, better, J s^{-1}. Similarly, acceleration can be written as metre per second per second and can be recorded as m/s^2 or m s^{-2}.
- The decimal point should be placed level with the feet of the numerals as in 5.1, 97.31.
- The comma is no longer used to separate digits in large numbers. They are divided into groups of three, e.g. 973 161 289 (not 973,161,289) from the right.

Numbers in SI units are often written to a power of 10 for convenience. Certain powers of 10 are indicated by prefixes which can be used with all of the SI units and derived units (Table 1.4).

Measurement of physical quantities cannot be separated from science activities. All branches of science use some instruments to measure quantities. Physical quantities should always have units, and the units must be correct, otherwise they have no meaning. For example, the correct expression for a length of 15 kilometres is l = 15 km **not** l = 15 or l = 15 kg. The type of instrument used for any particular measurement is determined by the accuracy required and the physical quantity to be measured. Amount of a substance is the only base quantity not measured by an instrument directly. Its value is measured indirectly, for example, by

Table 1.4 Decimal multiples and sub-multiples

Multiplication factor for the unit	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	alto	a

measuring its mass and then using the mass to calculate its amount.

Using scientific measuring instruments

It is important to accurately record data in experiments. Some measuring instruments and what they measure are shown in Table 1.5. Truthful and accurate measurements ensure that scientific results can be replicated and errors minimised. Using standardised procedures and accurate scientific measuring instruments enables scientists to produce consistent scientific results and helps in the formulation of new hypotheses, or proposed explanations of ideas, which expand the scientific knowledge base.

Length

The instruments used in measuring length are the **metre rule**, the **surveyor's tape** and the **ruler** (Figure 1.4). Short straight-line distances between two points can be measured on a figure with **vernier callipers**. Extremely short distances are measured with the **micrometer screw gauge**. The vernier callipers measure to a precision of 0.1 mm whereas the micrometer screw gauge can measure to a precision of 0.01 mm. The diameter of a piece of wire or the thickness of a sheet of paper or cloth can be measured using a micrometer screw gauge. This instrument is used mainly by engineers and metal fabricators.

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Table 1.5 Quantities and instruments used for measuring them

Quantity	Measuring instruments	Unit	Sub-units
mass	balances electronic balance	kilogram (kg)	gram (g) milligram (mg)
length	metre rule surveyor's tape pair of callipers vernier callipers micrometer screw gauge	metre (m)	centimetre (cm) millimetre (mm)
volume	measuring cylinder burette pipette	cubic metre (m^3)	cubic decimetre (dm^3) or litre cubic millimetre (mm^3)
time	stop-clocks and watches electronic clocks and watches	second (s)	millisecond (ms)
temperature	thermometer	Kelvin (K) degrees Celsius (°C)	
atmospheric pressure	aneroid barometer Fortins barometer	pascal (Pa)	
electric potential	voltmeter	volt (V)	millivolt (mV)
electric current	ammeter	ampere (A)	milliampere (mA)
luminous intensity	photometer	candela (cd)	
amount of substance		mole (mol)	millimole (mmol)

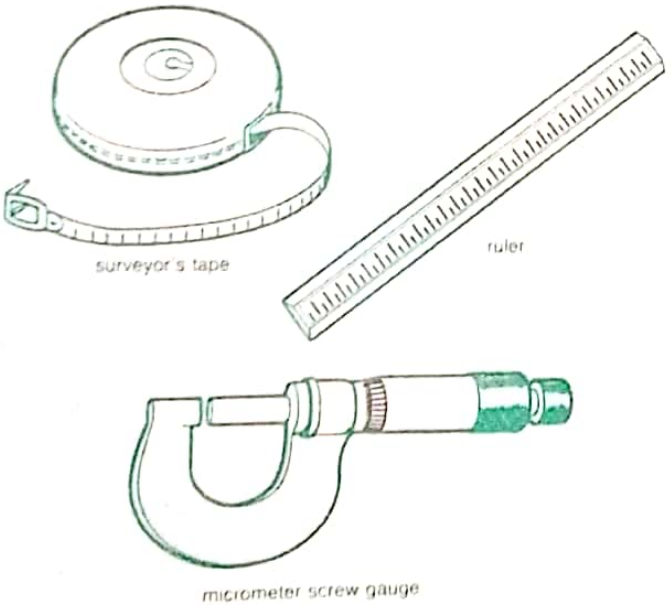


Fig 1.4 Some instruments for measuring length.

ACTIVITY 1 Measurement

1 Use a surveyor's tape, a metre rule or ruler to measure the length and breadth of your exercise books, table top, the classroom and the school football field. Calculate the area in each case.

2 Work in pairs and use a measuring tape to measure the following parts of your partner's body: waist, neck, wrist, leg, arm, height, foot, etc.

3 Measure the sides of three-dimensional objects, such as matchboxes and boxes of detergent, and calculate the volume.

Measurement of the huge distances in space is described in light years. A light year is the distance covered by light in one year. Light travels in a vacuum at 3.0×10^8 m s^{-1}.

Area

The area is a definite space covered on a plane figure. The area of the surface can be measured and calculated. The area of the surface may be rectangular, square, circular, triangular or spherical. In each case a specific formula is used. Your mathematics teacher will teach you about these.

The surface area of a regular shaped body is equal to length (l) × breadth (b) and can be calculated from these dimensions. Volume is calculated from area of base × perpendicular height. A pair of callipers is used to measure the external and internal diameter of a solid

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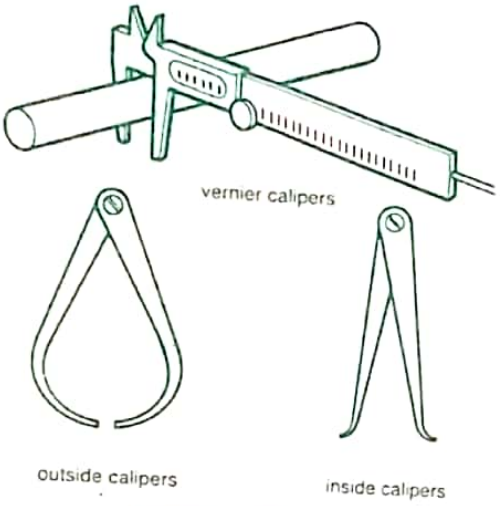


Fig 1.5 Callipers.

hollow object where rulers cannot be used directly (Figure 1.5). Usually made of hinged steel with an upper and lower jaw, the upper jaw is used to measure the external diameter and the lower jaw the internal diameter of circular objects. The distance between the two jaws is then measured using a ruler. Some callipers have no scale. However, vernier callipers have a vernier and main scale.

Volume

The volume of a body is the amount of space occupied by the body. It is measured in m^3 or cm^3. A body also displaces a volume of water exactly equal to its mass.

We obtain the volume of a rectangular solid regular object by its physical dimensions. The dimensions are measured and appropriate formulae are used to calculate the volume.

The volume of a rectangular wood or metal is equal to the product of its length, breadth and perpendicular height:

$$V = l \times b \times h$$

The volume of a cylindrical object = $\pi r^2 h$

Sphere = $4/3\ \pi r^3 h$
Cone = $1/3\ \pi r^2 h$
Pyramid = 1/3 area of base × height

The volume of an irregular object can be obtained by finding the volume of water displaced by the object. This can be done by using the overflow (Eureka) can experiment or a graduated cylinder.

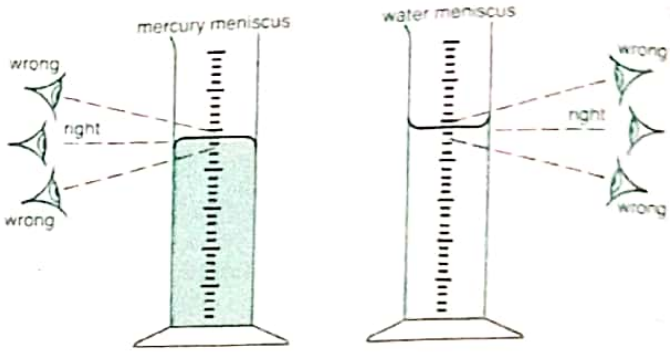


Fig 1.6 Correct reading of volume.

Rough measurements of volumes of liquids are made using a **measuring cylinder**. A measuring cylinder is calibrated and marked by the manufacturers. When liquid is poured into a graduated container, such as a measuring cylinder, the volume is read at horizontal eye level at 90° at the bottom of the meniscus (Figure 1.6).

The meniscus may bulge upwards, as occurs with mercury, or downwards, as occurs with water. Readings should be taken in a horizontal plane at 90° to the meniscus (at eye level).

The **pipette** is used to measure accurate fixed volumes of liquid. Other measuring instruments that can be used to measure a required volume of liquid include the **burette**, the **standard volumetric flask** and **graduated beaker** (Figure 1.7).

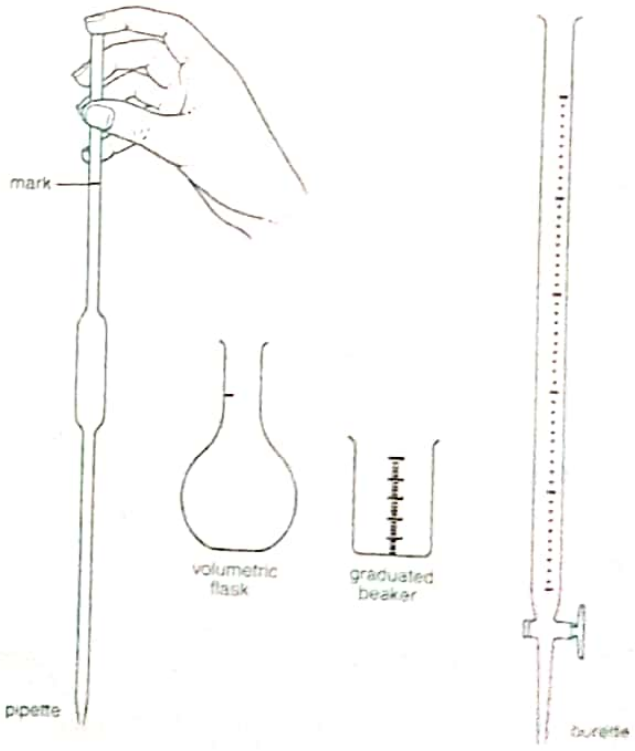


Fig 1.7 Instruments for measuring volume.

Time

Watches and clocks measure time. The base unit of time is the second. The multiples of the second are minutes, hours, days, months and years. An accurate measure of time can be produced by modern quartz, digital and electronic watches.

Mass

The mass of a body or the quantity of matter contained in a body can be measured in a science laboratory, a butcher's or vegetable seller's shop using a balance. Some chemical balances can compare masses to the nearest 0.01 gram while others are even more sensitive. The electronic **top pan balance** is a sensitive instrument for measuring mass. Other types of balances include the **lever arm balance**, **dial spring balance** and **spring balance** (Figure 1.8). A first class lever can also be used to compare masses where no measuring instrument is readily available. Spring balances and lever balances are used extensively to measure the mass of food items.

One instrument that is often used to measure weight is a **newtonmetre**. Weight is the measure of the Earth's pull on a body. It is a force and is measured in newtons (N), while mass is measured in kilograms (kg). The newtonmetre looks like a spring balance but is calibrated in newtons.

An object that weighs 60 N on the surface of the Earth will weigh 10 N on the moon because the force of gravity of the moon is only one-sixth that of the Earth.

A floating body will sink to different depths in different liquids, as its weight will be the same in liquids of different densities. This is the principle on which **hydrometers** are built. A hydrometer is a weighted bulb with a long marked stem. The weight keeps the hydrometer erect and it sinks to a mark on the stem, showing the density of the liquid (Figure 1.9). Hydrometers are used to show whether a car battery is charged (by measuring the density of the acid in the battery), and to measure the density of alcohol and other liquids.

We often need to measure things we cannot actually see, like temperature, electricity, pressure and wavelength, all of which play a role in our daily lives. People have therefore had to find a way of measuring these, and through scientific investigation have

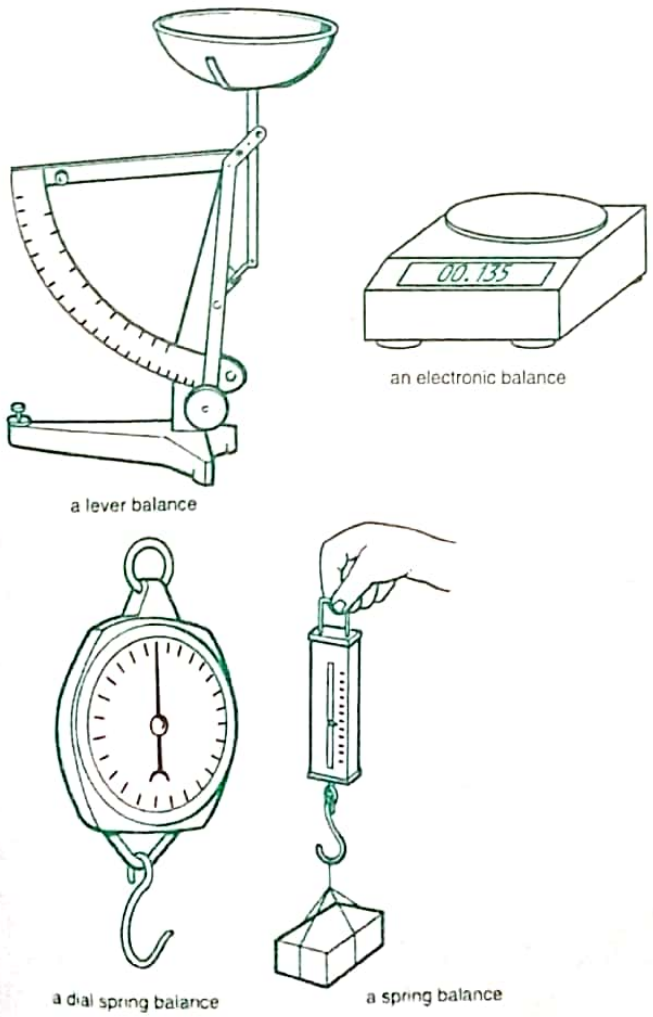


Fig 1.8 Balances.

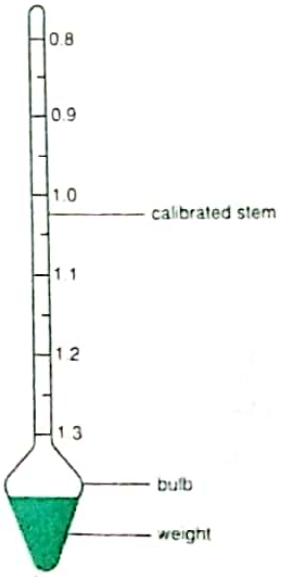


Fig 1.9 A hydrometer.

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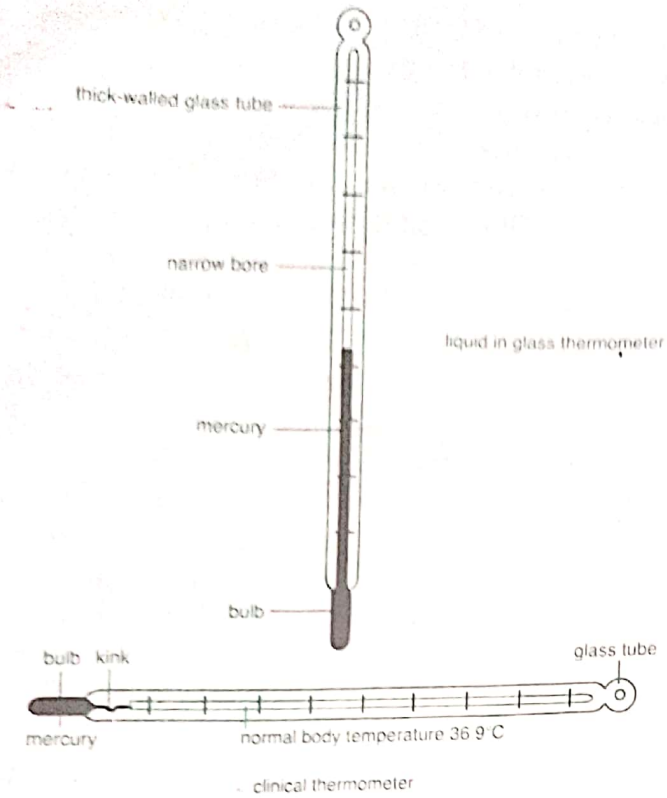


Fig 1.10 Thermometers.

developed instruments that can give visual readings on a non-visible quantity. You will be familiar with the thermometer (Figure 1.10), which you will use in Activity 2. The increase in temperature, which you cannot see, is recorded by a 'man-made' scale so that we can find the temperature of water as it is heated to boiling point. Digitised thermometers are now available in many hospitals and clinics.

ACTIVITY 2 Measurement of temperature

Caution: Boiling water can burn the skin.

1 Weigh an empty beaker (M_1).

2 Fill the beaker three-quarters full with ice blocks.

3 Weigh the beaker and contents (M_2).

4 Measure and record the initial temperature of the ice blocks.

5 Gently heat the contents of the beaker with a Bunsen burner and record the temperature every minute until the water has boiled for 5 minutes.

6 Plot a graph of the recordings with time on the horizontal axis and temperature on the vertical axis.

7 Describe the shape of the graph and identify the points at which the ice melted and at which the water boiled.

ACTIVITY 3 Measurement of pulse and body temperature

1 Working with a partner, take the pulse rate and the body temperature of the partner (a) at sitting position, (b) after jumping for 2 minutes, (c) after running around the football field or a specific distance. Figure 1.11 shows you how to take the pulse and temperature.

In which of the activities is the pulse rate fastest?

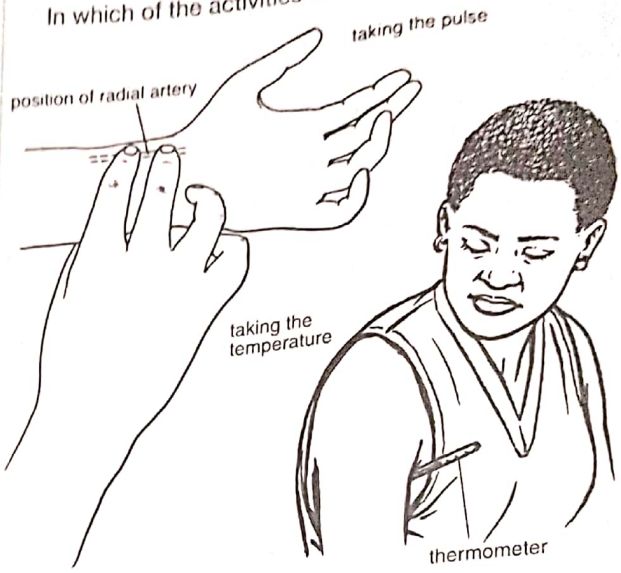


Fig 1.11 Taking a pulse and temperature.

Is the temperature the same for both partners? Is it the same after each activity?

2 Compare your recordings with those of other groups and give reasons for the changes in pulse rate and temperature, if any.

3 Measure the temperature of a partner every day for one week (a) before morning assembly, (b) at about 2 p.m. Compare the temperatures. Suggest reasons for the change in temperature, if any.

4 Plot a histogram of the body temperature against the time of day that temperatures were read.

5 Class discussion: has the body temperature change anything to do with (a) the time of day? (b) before or after eating? (c) any sickness?

Velocity

Speed is a scalar quantity whereas velocity is a vector quantity. A scalar quantity has a magnitude only but a vector quantity has both magnitude and direction.

Speed is the rate of change of distance whereas velocity is the rate of change of displacement. Both speed and velocity are measured in metres per second ($m\ s^{-1}$) but a direction is stated in the case of velocity.

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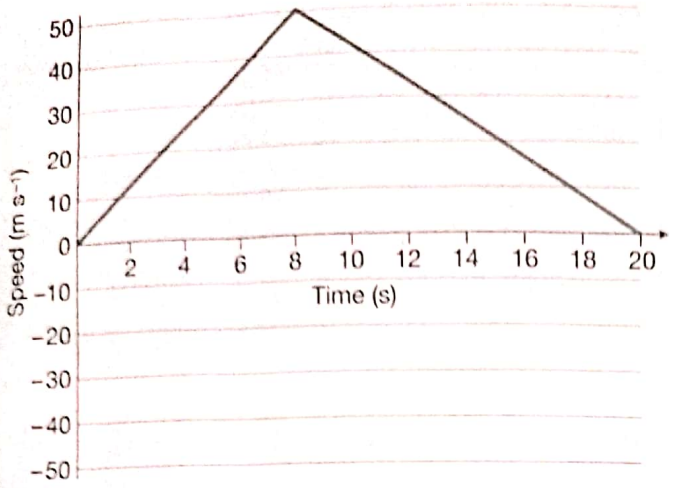


Fig 1.12 Speed–time graph.

We can illustrate both speed and velocity with a speed–time graph (Figure 1.12) and velocity–time graph (Figure 1.13). An arrow is shot vertically upwards with a velocity of 50 m s^1. The arrow rises for 10 seconds and slows down under the pull of gravity until its velocity is zero. Note that the motion of the arrow was upwards first and later downwards until it stopped.

The speed–time graph takes no account of the direction of motion.

The area under the speed–time graph provides for the distance covered and can be calculated as follows:

$$\text{Area} = \frac{(1/2 \times 10 \times 50)}{250} + \frac{(1/2 \times 10 \times 50)}{250}$$
$$= 250 + 250$$
$$= 500 \text{ m}^2$$

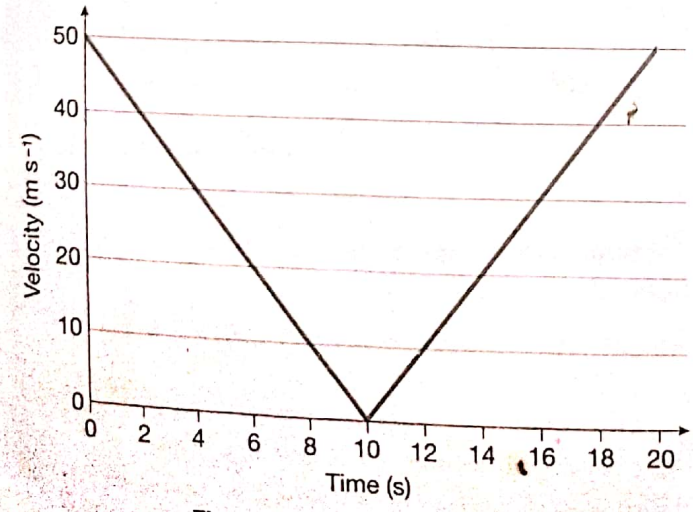


Fig 1.13 Velocity-time graph.

The area under the velocity–time graph gives the displacement of the arrow

$$\text{Area} = \frac{(1/2 \times 10 \times 50)}{250} + \frac{(1/2 \times 10 - 50)}{250}$$
$$= 250 - 250$$
$$= 0$$

Density

The density of an object is the ratio of the mass of the body and its volume. It does not make sense to say that 'aluminium is lighter than lead'. A large piece of aluminium will, of course, be heavier than a small piece of lead. What we really mean is that a piece of aluminium of a particular volume will be lighter than a piece of lead of the same volume. The mass per unit volume of a material is called its **density**. The density of aluminium is less than the density of lead.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \text{ or } \rho = \frac{m}{V}$$

The SI unit for density is kg m^{-3}. Density helps engineers to determine the type of material to be used in particular construction work. For example, aeroplanes are built with metals of low density.

ACTIVITY 4 Determining the density of an object

1 Measure the mass m of the object using a top pan balance.

2 Using a graduated cylinder of 5000 m^3 measure a volume of water. Mark the level of water as V_1.

3 Place the object into the water and mark the new volume as V_2.

4 Find the volume of the object using:

$V = V_2 - V_1$ (cm^3 or m^3)

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{m}{(V_2 - V_1)}$$
$$= m/V$$

Materials that are less dense than water, such as wood and cork, will float on water; materials that are denser than water, such as iron and stone, will normally sink. Table 1.6 gives the densities of some common substances.

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Table 1.6 The densities of some common substances

Substance	Density/ kg m^{-3}	Density/g cm^{-3}
paraffin oil	800	0.8
water	1 000	1.0
glass	2 600	2.6
aluminium	2 700	2.7
mild steel	7 000	7.0
brass	8 000	8.0
silver	10 500	10.5
lead	11 000	11.0
mercury	19 300	19.3

Relative density

The **relative density** of a substance is its density compared with that of water.

$$\text{Relative density} = \frac{\text{density of substance}}{\text{density of water}}$$

Relative density can also be described as the mass of a certain volume of the substance divided by the mass of an equal volume of water. As relative density is a ratio of two densities it has no units. For example, the relative density of aluminium is 2.7, while that of paraffin oil is 0.8. A summary of the differences between density and relative density is given in Table 1.7.

Table 1.7 Difference between density and relative density

Density	Relative density
1 Density is a measured quantity and has units	1 Relative density is a comparison between two measured substances and has no unit
2 Density is the ratio of the mass of a substance and its volume	2 Relative density is a comparison between the mass of a substance and the equal mass of water

ACTIVITY 5 Finding the relative density of a regular object

1 Use vernier callipers to measure the dimensions of a regular block.
2 Find the volume of the block using appropriate formulae.
3 Find the mass of the block (in grams) using a balance.
4 Calculate the density of the block using the formulae $\frac{m}{V}$.
5 Convert the value of your calculated density from g cm^{-3} to kg m^{-3}.
6 Find the density of water and calculate the ratio of the density of the object and water.

ACTIVITY 6 Finding volume of a solid by displacement

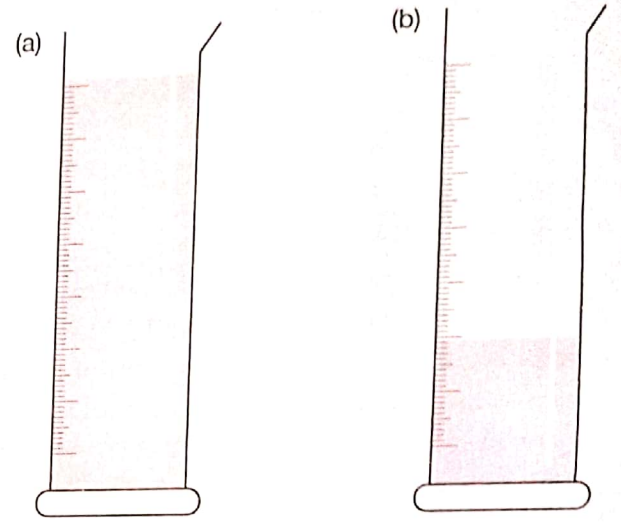


Fig 1.14 Finding volume by displacement **(a)** initial volume (V_1) **(b)** second volume after immersing solid (V_2).

1 Fill a measuring cylinder with water as shown in Figure 1.14.
2 Measure the volume of water (V_1)
3 Lower a solid object into the water in the measuring cylinder.
4 Measure the new level of water (V_2)
5 Calculate the volume of the solid object from the difference between V_1 and V_2.

ACTIVITY 7 Finding the density of an irregular object

1 Find the volume of a solid by the displacement method described in Activity 6.
2 Calculate the density using the formula Density = $\frac{\text{mass}}{\text{volume}}$.
3 Convert your density from g cm^{-3} to kg m^{-3}.

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ACTIVITY 8 Using density bottle to determine relative density

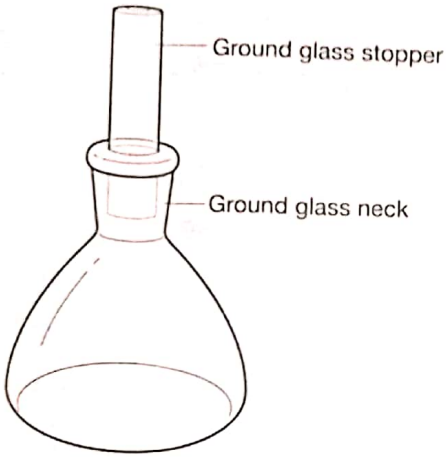


Fig 1.15 A relative density bottle.

1 Find the mass of an empty relative density bottle (Figure 1.15) using a balance (m).
2 Fill the bottle with liquid of unknown density and weigh (m_1).
3 Empty the density bottle and dry it. Refill it with water and weigh it (m_2).
4 Use the following formula to calculate the relative density of the liquid:

$$\text{Relative density} = \frac{\text{mass of liquid}}{\text{mass of equal volume of water}}$$

$$= \frac{m_1 - m}{m_2 - m}$$

ACTIVITY 9 Standardised procedures in science

Work in groups to discuss why it is important that scientists use standardised procedures. Think about replication and checking of results, and accuracy and consistency of the scientific method.

Force

A force is a push or a pull. Forces are also vector quantities, which means that they act in a specific direction. A force is needed to accelerate an object, that is, to cause the object to move faster or to slow down. The direction of the acceleration is always in the direction of the force. Force is measured in newtons.

The newton (N) is a force which will cause a mass of 1 kilogram to accelerate 1 m s^{-2}.

$$\text{Force} = \text{mass} \times \text{acceleration or } F = ma$$

Force can be grouped into:
- contact force (friction)
- non-contact forces (electromagnetic).

Work and energy

Work is done when a force moves through a distance in the direction of the force.

$$\text{Work} = \text{force} \times \text{distance}$$

Work is measured in newtons (N) and distance metres (m). Therefore the unit for work is Nm which is the same as the joule.

Energy is directly proportional to the work done. Energy of 1 joule is involved when a mass of 1 kg is moved through a distance of 1 metre. Both work and energy are vector quantities. The unit for energy and work is joule (J).

Quantity of electricity

Electric current is defined as the total charge transferred per second. The total charge transferred, Q when a current I is transferred for a time of t seconds is therefore:

$$Q = It$$

The unit of charge is the coulomb, C.

Electric resistance (R)

The wire through which an electric current flows impedes or resists the flow of current. Appliances such as bulbs and electric irons resist the flow of current as well as the fuses in a circuit. Resistors are devices which oppose or resist the flow of current.

Resistance is measured in ohms (Ω). A conductor has a resistance R of 1 ohm if a potential difference V of 1 volt causes a current I of 1 ampere to flow through it.

The relation, therefore, is $V = IR$.

Potential difference (V)

The flow of electric current produces varied physical effects which are applied in transforming electrical energy into other forms of energy, such as heat and sound. The energy converted per unit charge in the load is the potential difference (pd) across the load.

Potential difference is measured in volts (V).

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Power (P)

Power is the rate at which work is done. J. Prescott Joule discovered that the rate of production of heat energy in a wire is proportional to the square of the current, I.

$P = I^2R$, where P = power, I = current and R = resistance or $P = IV$

Heat (Q) = power × time = $I^2R \times t$

or $Q = I^2Rt$

Energy used or produced at the rate of 1 joule per second is a power of 1 watt. The unit for power is the watt (W).

Self check

1 Define density and relative density.

2 Describe how to determine the relative density of a liquid.

3 Design an experiment to determine the relative density of an irregular stone using the overflow can.

4 What is meant by the following terms:
- **a)** potential difference
- **b)** resistance
- **c)** power
- **d)** force.

5 Distinguish between a scalar and a vector quantity. Give three examples of each.

6 Enumerate four basic quantities showing how they are measured and the instruments used for measurement.

7 State three precautions to be taken when using a meter rule to measure the length of an object.

8 List four methods to determine the volume of a substance.

9 Explain why there is no definite formula for determining the volume of substances.

10 **a)** How is the density of a solid object determined?
b) Explain why the density of materials is essential in engineering activities.

11 Distinguish between potential difference and resistance offered by a load.

12 State the unit for each of the following quantities and show whether it is a vector quantity or a scalar quantity:
- **a)** length
- **b)** thermodynamic temperature
- **c)** electric resistance
- **d)** volume
- **e)** force
- **f)** velocity.

13 What is the difference between speed and velocity?

14 Explain the following terms:
- **a)** coulomb
- **b)** potential difference
- **c)** potential difference
- **d)** resistance.

15 **(a)** What is:
(i) a base physical quantity?
(ii) a derived physical quantity?
(b) Write the symbol for each of the following quantities and classify each as a base or derived quantity:
(i) force
(ii) length
(iii) density
(iv) amount of substance
(v) luminous intensity
(vi) power.
(c) Write down the symbols for the units of all the physical quantities stated in (b).

16 Comment on the following statements:
- **a)** 'The volume of oil is ten'.
- **b)** 'The amount of substance of sugar is 10 grams'.

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3 Diversity of living and non-living things

Learning objectives

After studying this unit, you should be able to:

1 differentiate between living and non-living things
2 classify living and non-living things
3 outline the general characteristics of the five kingdoms of living things.

Background information

Books in libraries are arranged in one of two ways – either by subject or in alphabetical order of authors' names. These arrangements are made so that a book can quickly and easily be located.

There are many other things, both living and non-living, that have been collected into groups for a particular purpose and on the basis of a particular feature or property.

- Grouping of objects is known as **classification**.
- Classification of objects makes them easy to work with or study. It helps in recall (remembering) and understanding.
- Classification helps scientists in their work. For example, it helps agricultural scientists to select the best varieties for planting to ensure the greatest yield.

Classification is very important to scientists. Biologists have described about one and a half million kinds of living things. This number is always increasing because new living things are frequently being discovered. These living things show many differences. Without classifying them, biologists would find it difficult, if not impossible, to handle knowledge about them.

One hundred and three chemical elements are now known to scientists. All of these elements differ from each other. Though the number of known elements is very small compared to that of living things, it is not practical to study them individually. They have to be classified for easier study, recall and to make predictions.

Diversity means the wide range of differences that a scientist can see when looking at a large number of different organisms. For example, compare an iroko tree (odum) to a rose flower plant, or an ant to a horse.

Living and non-living things

There is a great number of both living and non-living things on Earth. They all differ in shape, colour, size, chemical composition and many other features. However, they are all related to each other. Living things become non-living things when death occurs. In spite of the fact that they are adapted to their environment, living things need non-living things in order to survive. For example, some organisms break down dead organisms and waste materials into mineral salts. Plants use the salts, together with some other inorganic materials, to manufacture food. Both plants and animals depend on the manufactured food for survival. Humans also manufacture goods using both living and non-living things. Some goods are important in life.

Differences between living and non-living things

There are certain basic characteristics that distinguish living things from non-living things. These are the seven **life processes**:

- **nutrition** – taking in or manufacturing food in order to carry out other life processes

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- **respiration** – releasing the energy from food with or without the use of oxygen
- **excretion** – the removal of toxic (poisonous) waste metabolic products from the body
- **irritability** – response to stimuli (singular stimulus), i.e. changes in the surroundings
- **movement** – change of position of the whole body or part of the body
- **growth** – irreversible increase in size and weight
- **reproduction** – ability to make more of the same kind.

Unicellular organisms split into two or more parts (asexual reproduction); in higher organisms reproduction involves the fusion of special cells called gametes, to form a zygote which grows into a new individual (sexual reproduction).

Non-living things can show some of these characteristics, e.g. a car can move, a crystal can grow and a fire alarm is sensitive. However, only living things show all these characteristics in one organism. Reproduction is unique to living organisms, for no non-living thing is capable of reproducing.

ACTIVITY 1 Comparing living and non-living things

1 The following list contains living and non-living things:

rat	desk	boat	car	sun
water	air	smoke	tree	snake
brick	plane	bird	fish	mosquito

Think about each one carefully.

2 Copy Table 1.8 into your book. Place the items in the list in the first column. Place a tick in each of the next seven columns as appropriate to each item. In the end column, say whether the item is living or non-living. One item has been done for you as an example.

3 Add some items of your own to the first column and fill in the rest of the table as for the others.

ACTIVITY 2 Observing living organisms in the school environment

1 Explore the school environment to observe the ways living organisms move, feed, grow, respire, reproduce and respond to stimuli.

2 Read your observations and discuss with the class.

Classifying things

The history of science shows that scientists realised the need for classification a long time ago – at the time of the ancient Greeks. Aristotle (384–322 BC) was a Greek biologist who produced the first classification of living things. He classified animals by looking at the way they moved, that is, he put together animals that fly or run or swim, etc. Thus, flying animals would include bats, insects, birds and flying fish. This method of grouping is not a good one because the members of the group do not have anything in common except movement. The group members are said to have no natural relationship. It is a less useful method of classification than others.

Aristotle used appearance and size as a way of classifying plants. He grouped plants as herbs, shrubs or trees. A herb is a plant whose shoot system dies off at the end of the growing season. An example is grass. A shrub is a plant that is smaller than a tree. It has a woody stem. Unlike a herb, the part above the ground does not die off at the end of each growing season. Its main stem divides near the base into many branches. Hibiscus is one example of a shrub. Aristotle's way of classification was used for nearly 2000 years.

The Swedish naturalist, Carolus Linnaeus (1707–78), began a system of classification based on natural relationships. He started his classification from the smallest group of organisms that can interbreed (mate) to produce offspring (young) which are capable of reproducing. He called this group of organisms the **species**. Linnaeus' system of classification, which is still in use today, is called the **natural system of classification** because it puts all organisms with the same structure (body plan) together.

Table 1.8 Table for Activity 1

Item	Life processes possessed							Living or non-living
	nutrition	respiration	excretion	irritability	movement	growth	reproduction	
car	√		√	√	√	√	x	non-living

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Classification of elements, unlike that of plants and animals, became necessary only some 200 years ago when new elements were discovered. About 55 elements and their properties were known by 1830. These elements showed similarities and differences in their properties. Elements that were alike were put into groups and given family names, such as the **alkali metals** and the **alkaline earth metals**. In 1860 Dimitri Mendeleev, a Russian scientist, produced a better classification of the elements. He predicted that some of the families of elements contained elements yet to be discovered. He also discovered that the properties of the elements changed gradually as their atomic number increased. Again, he frequently came across an element that showed similar properties to an earlier one. These two discoveries made him try to arrange the elements so that those with similar properties came under one another in a vertical column. Another point about his arrangement was that the elements in any given horizontal row or period showed smooth and regular changes in properties in passing from one element to another. This is why his groupings of the elements is called **periodic classification**.

The basis for classification

Scientists use a classification system to put things into groups. A classification system is a set of labels (names) that are used to group things. The labels stand for properties or features. The properties or features may also be called characteristics. Things in the same group have similar properties that are different from the properties of any other group.

A good classification system is one that allows existing information to be sorted, new information to be added and patterns to be spotted.

Classification in biology

There are different methods of classifying biological information. The Linnaeus classification system is based on the body plan of organisms. Organisms are grouped on the basis of how their bodies are built.

Biologists find it useful to make a key when classifying. For example, if a botanist wishes to classify leaves, it may be necessary for them to consider the appearance of the leaves. The botanist would then develop a key by asking questions such as:

- Are the tips pointed or rounded?
- Are the edges smooth or jagged?
- Are they single pieces or is each divided into parts?
- Are the veins parallel or not?

A key can then be developed as shown in Figure 1.16. Note that leaves with tips that are not pointed can also be grouped like those with pointed tips. Another type of key is the numbered key, which can be used to identify the vertebrates illustrated in Figure 1.17.

1	Warm blooded	go to 2
	Cold blooded	go to 3
2	Possesses feathers	Aves (birds)
	Possesses hair	Mammalia
3	Possesses fins	Pisces (fish)
	No fins	go to 4
4	Moist, naked skin	Amphibia
	Dry, scaly skin	Reptilia

ACTIVITY 3 Classifying vertebrates

Using the key, put the vertebrates numbered 1–8 in Figure 1.17 into their correct classes.

ACTIVITY 4 Classifying arthropods

Using the features given in Figure 1.18, identify which class each of the organisms numbered 1–8 in Figure 1.19 belongs to. As a hint, look at the number of legs, the divisions of the body and the number of antennae.

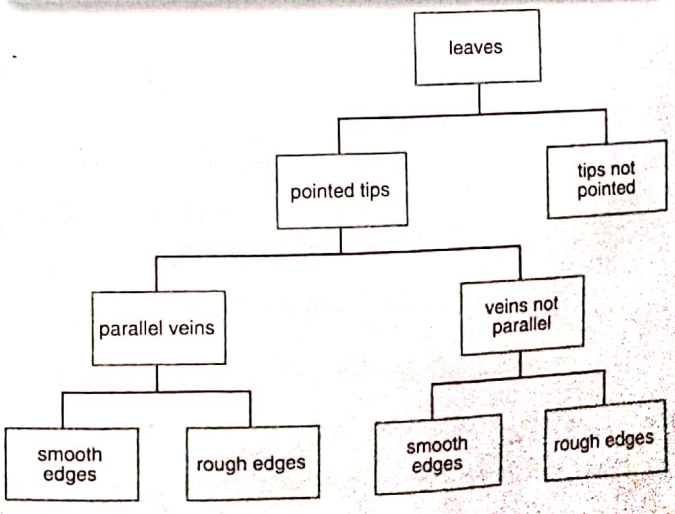


Fig 1.16 Grouping leaves according to appearance using a classification key.

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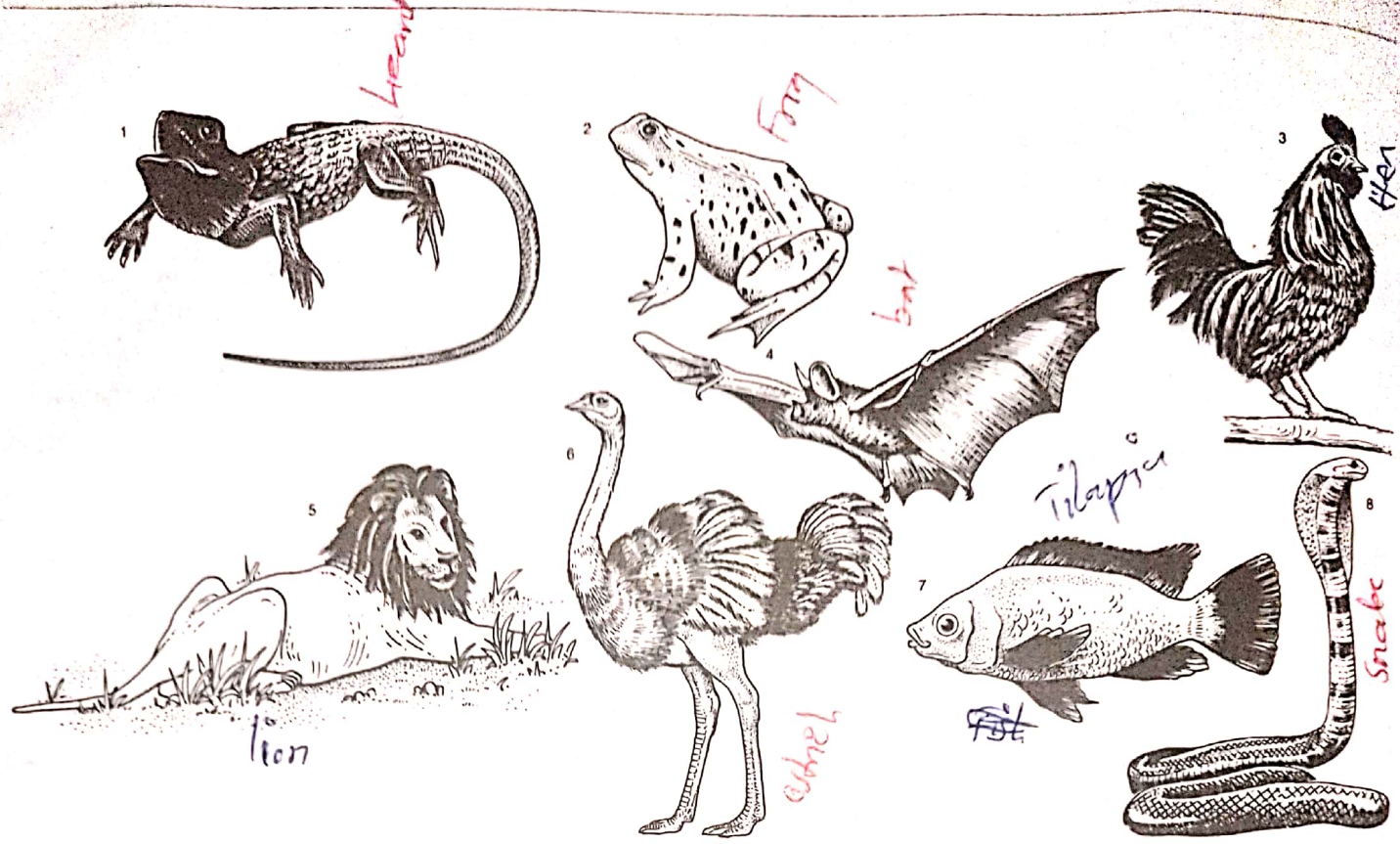


Fig 1.17 Vertebrates.

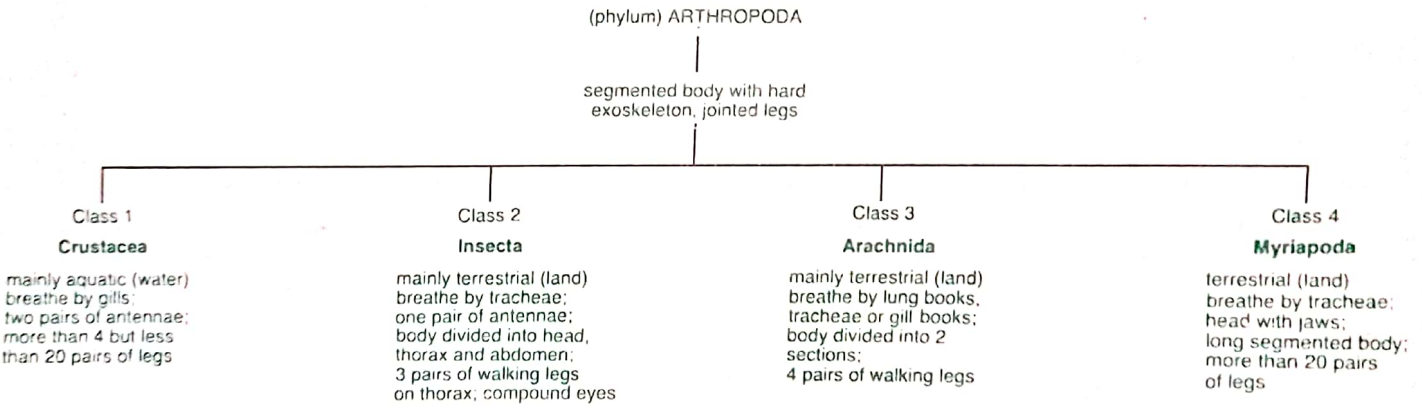


Fig 1.18 Classes of arthropods.

ACTIVITY 5 Classifying laboratory apparatus

The drawings in Figure 1.20 show some of the apparatus you may find in the laboratory.

1 Construct a table comparing four features of these pieces of apparatus.

2 Using your table to help you, construct a dichotomous key enabling each piece of apparatus to be distinguished from the other.

The name that is given to each group of organisms in the Linnaeus natural system of classification is shown in Figure 1.21. Members of each group have some features that are similar. These common features distinguish the group from any of the other groups. Similarities in each group increase as the 'ladder' is descended. Thus organisms at the same level (or each rung of the ladder) resemble each other more than those on a higher level. The resemblance becomes greatest at the bottom of the ladder. This is the **species** level. Non-biological items can also be classified, as shown in Activity 5.

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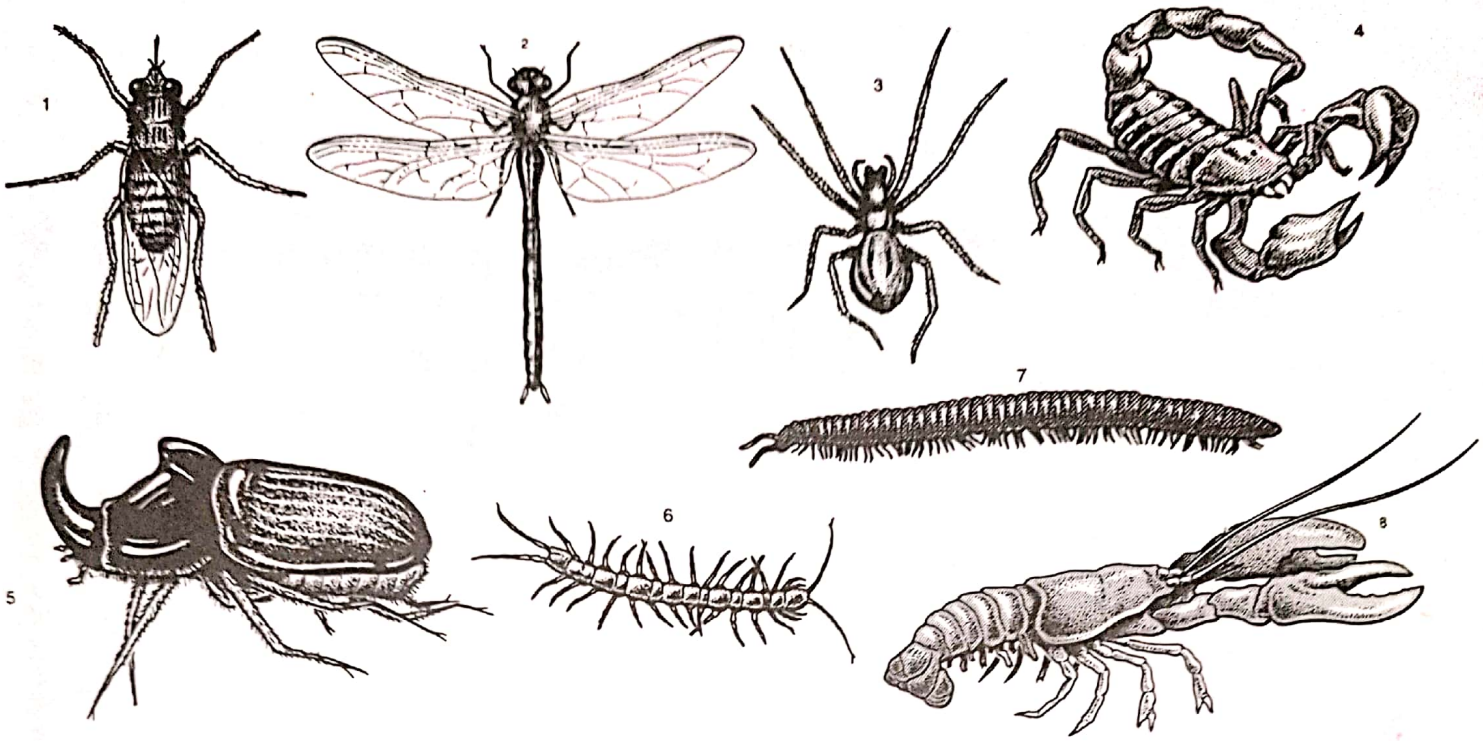


Fig 1.19 Examples of arthropods.

Organisms at the **species level** are so alike that members can mate and produce offspring (young) that are fertile.

On the other hand, organisms at the Kingdom level (or at the top of the ladder) show the least resemblance. There are more different kinds of living things at this level than at any other level. Note that each level is made up of all those below it on the ladder. For example, a Kingdom is made up of several smaller groups called phyla (singular phylum). Many species make up a genus (plural genera). Figure 1.22 shows how humans are classified.

The **binomial** system of nomenclature refers to a Linnaeus system in which every organism is given a

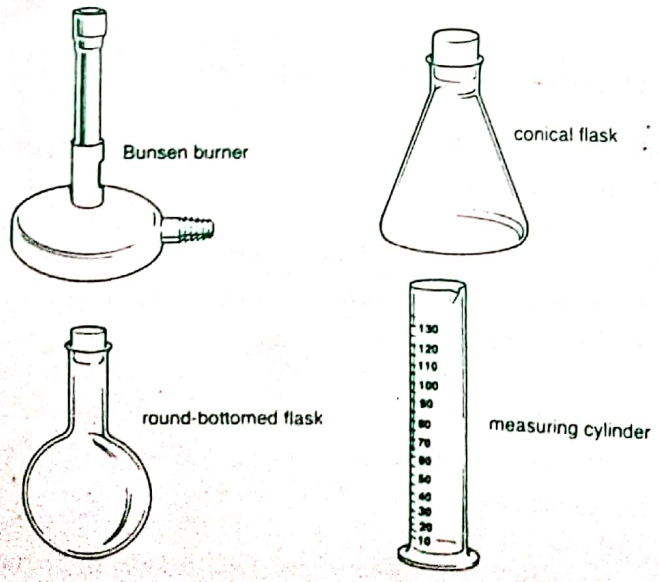


Fig 1.20 Laboratory equipment.

KINGDOM	Organisms may not have common features
PHYLUM	
CLASS	
ORDER	
FAMILY	
GENUS	
SPECIES	Organisms have many common features

Similarity within the group increasing

Fig 1.21 The Linnaeus system of classification for living organisms.

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Fig 1.22 Classification of man. Human beings are so alike they can interbreed.

two-part Latin name. The first part of the name is the genus to which the organism belongs. It always begins with a capital letter. The second part is the species to which the organism belongs. This name always begins with a small letter. The Latin names are still used today and ensure that biologists all over the world can identify living organisms in the same way. Examples of the two-part names are as follows:

Genus	Species	Common name
Homo	*sapiens*	man
Canis	*familiaris*	domestic dog
Gallus	*domesticus*	house fowl
Magnifera	*indica*	mango

Both names are printed in italics or are underlined. The genus name can be shortened. Thus *Homo sapiens* can be written as *H. sapiens*. The genus name can also be used alone, so human beings are said to belong to the genus *Homo*.

Reasons for classifying living things include:

- allows biologists to identify and follow similarities and differences in organisms
- allows any one group to be described using one or a few words
- allows new organisms to be identified and classified
- forms a common pool of knowledge that allows easy communication between all biologists.

Classification in chemistry

The system of classification of the elements is called the **periodic system**. The elements are arranged in order of increasing atomic number or the number of electrons in an atom of each element. Periodicity is the regular occurrence of similar chemical and physical properties with increasing atomic number of elements. The **periodic table** is an arrangement of the elements in order of increasing atomic number so that elements with similar properties are placed in vertical columns (groups) or horizontal rows (periods).

All modern forms of the periodic table are based on the original idea of Mendeleev. Figure 1.23 shows an outline of one form of the periodic table. A full copy

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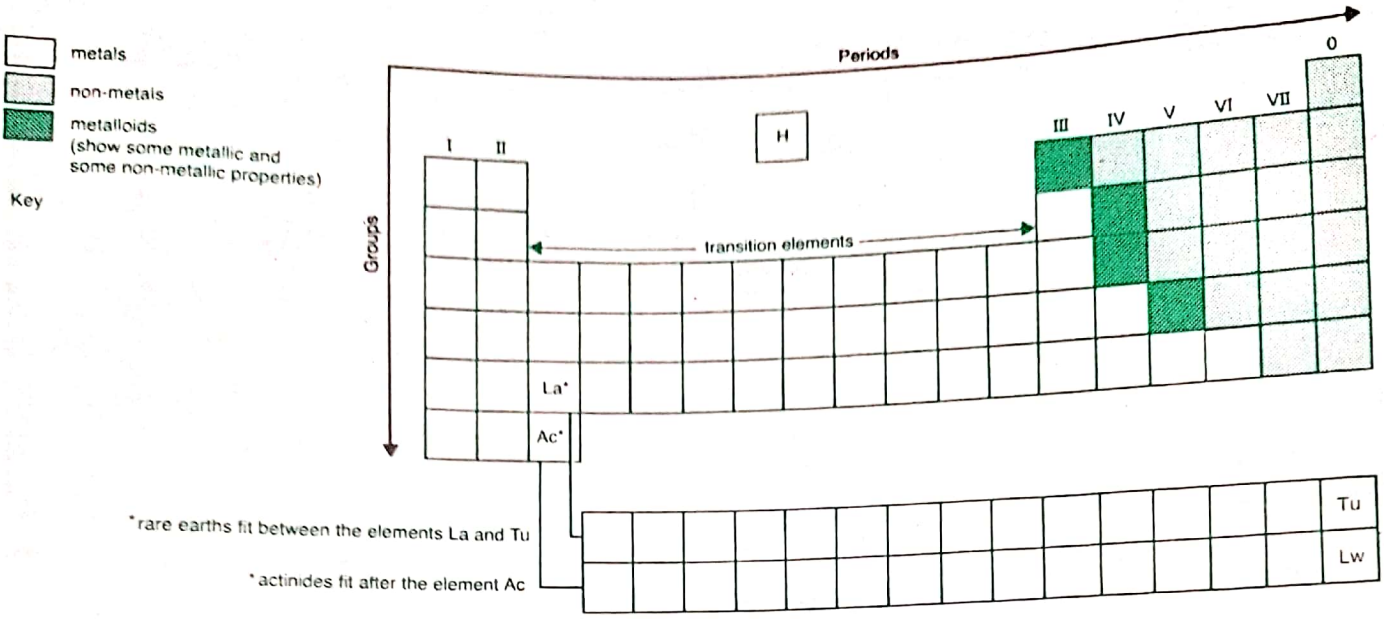


Fig 1.23 An outline of the periodic table.

can be found in Appendix III. The Roman numbers I to VII, and 0 stand for the eight vertical columns or **groups**. The horizontal rows are called **periods**. There are seven of these periods.

There is a change from metallic to non-metallic characteristics in each period as shown in the key in Figure 1.23. An actual example can be taken from period 3 in Appendix III. Sodium (Na) and magnesium (Mg) are metals; silicon (Si) has some properties that put it between metals and non-metals. Phosphorus (P), sulphur (S) and chlorine (Cl) are all non-metals.

ACTIVITY 6 To prepare a periodic table of the first 18 elements

1 Draw a large and clear outline of the periodic table as shown in Figure 1.23.

2 **a)** With the help of Appendix III, fill in the symbols of the first 18 elements.
b) Group the elements into metals, non-metals and metalloids.
c) What groups and periods do these elements belong to?

3 Make a list of elements that have both metallic and non-metallic properties.

4 Compare your work with that of your friends.

There are two disadvantages of classifying the elements into metals and non-metals:

- Some elements – the metalloids – do not fit into the classification. Boron (B), for example, has most of the non-metallic properties but melts at a very high temperature, which is a characteristic of metals.

General characteristics in biological classification

A recommended new version of the classification system puts all organisms into five groups:

- Kingdom Prokaryotae (bacteria)
- Kingdom Protoctista (protozoa and algae)
- Kingdom Fungi (fungi)
- Kingdom Plantae (plants)
- Kingdom Animalia (animals).

Examples of organisms from each of these kingdoms are given in Figure 1.24. Members of each kingdom have various common characteristics. These are described below, together with some examples (see also Figure 1.25).

- **Kingdom Prokaryotae (bacteria, including cyanobacteria)** – Most are microscopic – about one micrometre (μm) in diameter. They have no nucleus

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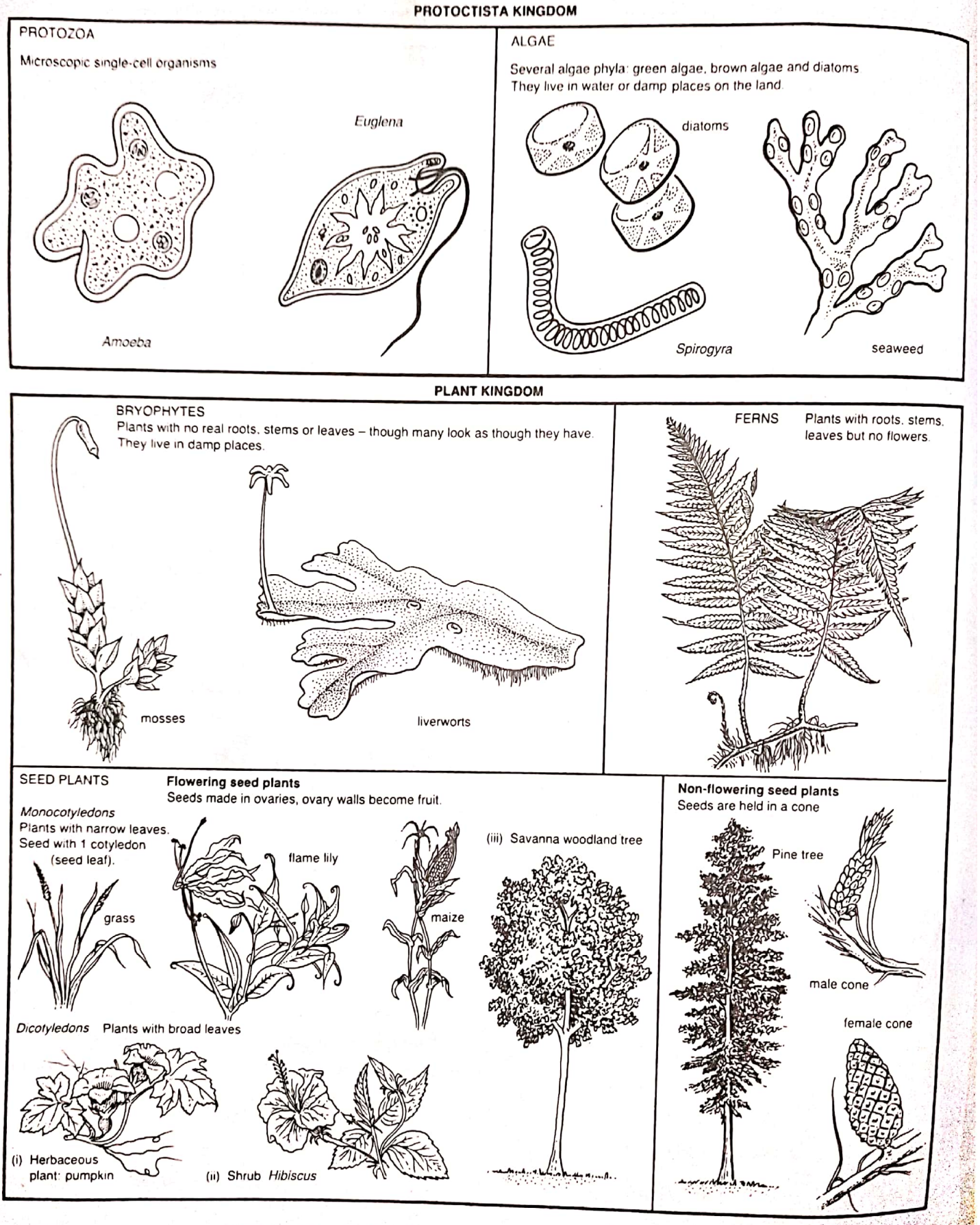


Fig 1.24 The classification of living organisms into five kingdoms.

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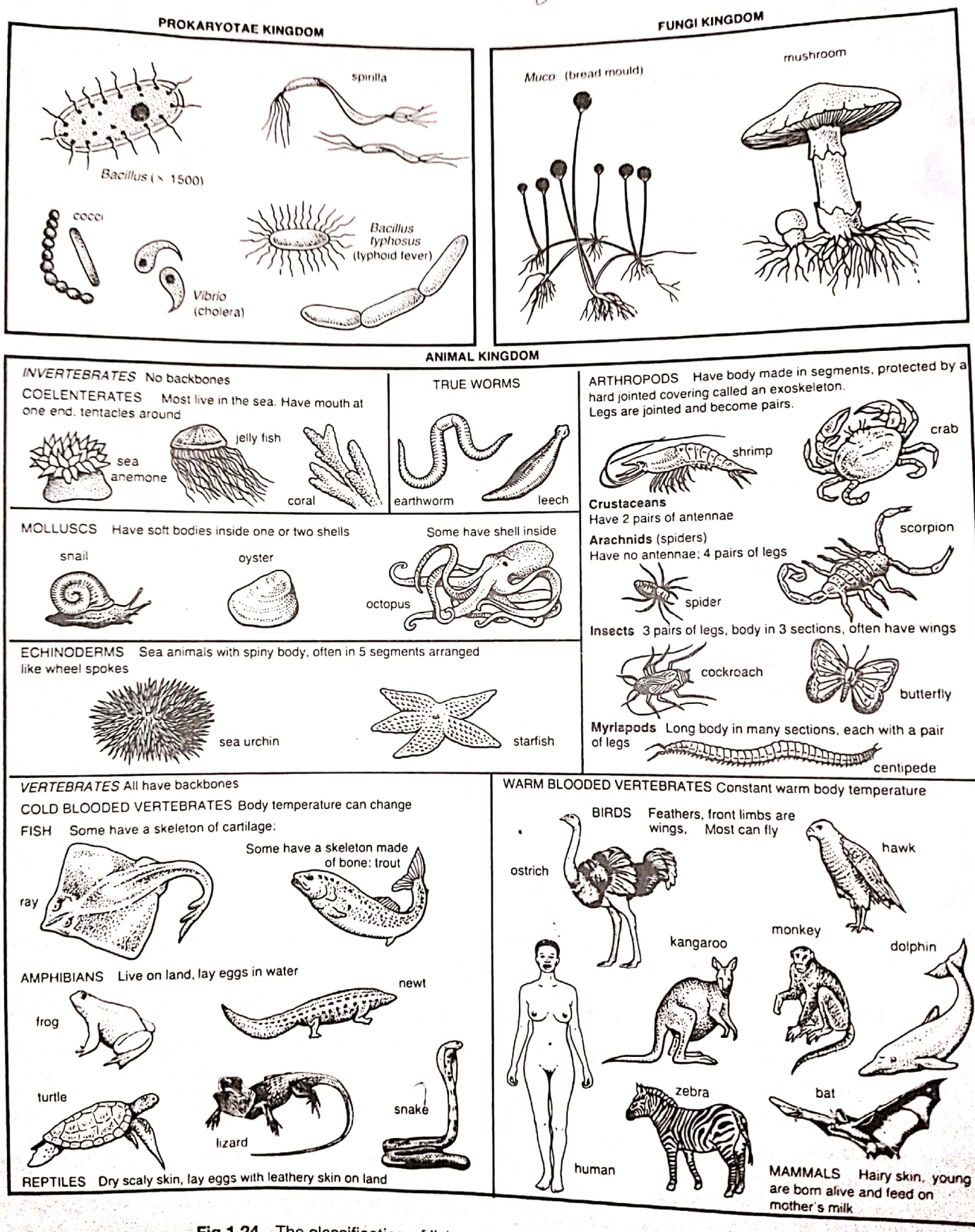


Fig 1.24 The classification of living organisms into five kingdoms. *(continued)*

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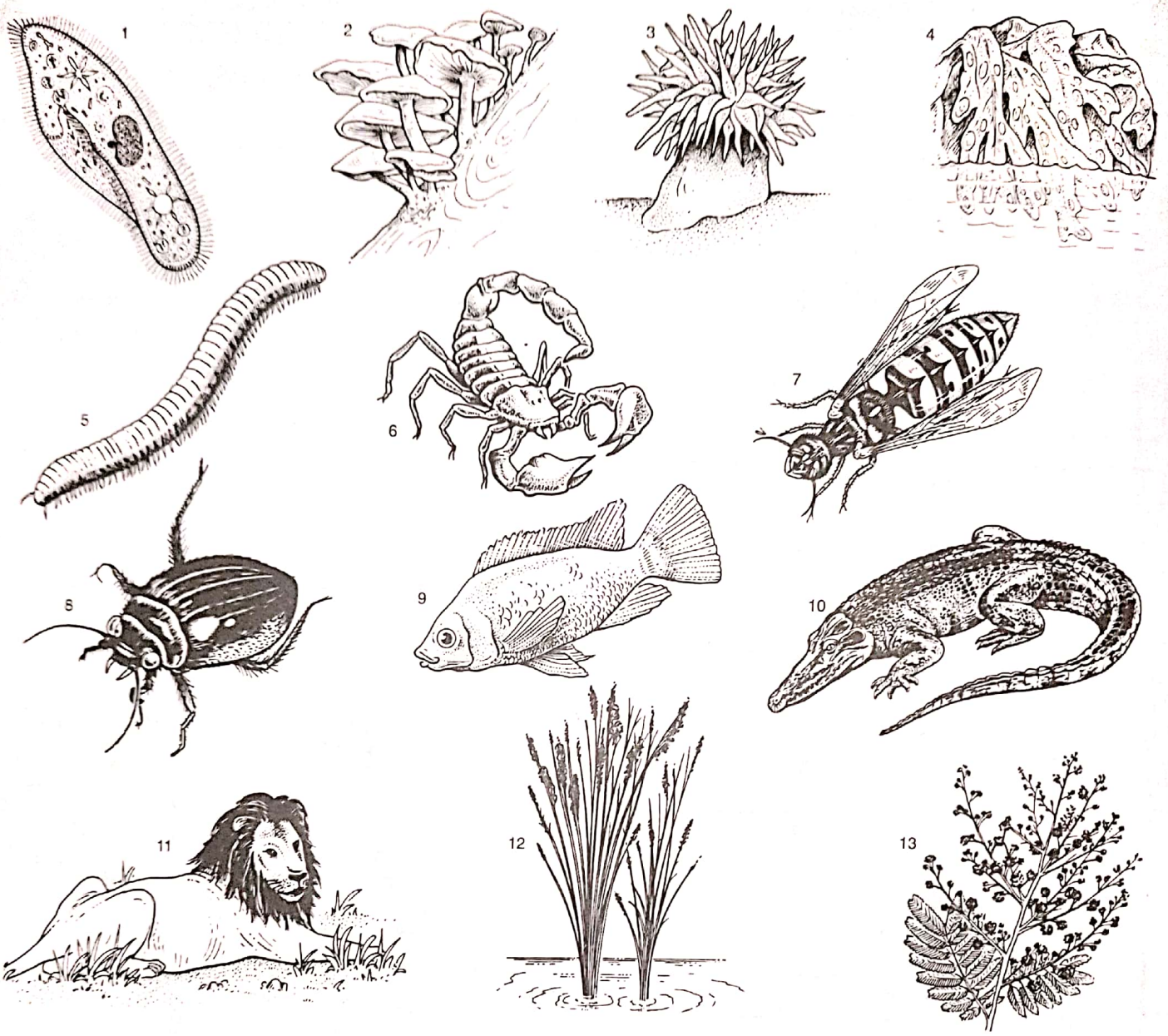


Fig 1.25 Examples of animals and plants.

and no membrane-bound organelles. The cytoplasm is surrounded by a cell wall. Many possess one or more flagella (thin, whip-like structures) which enable them to move, e.g. *Escherichia coli*.

- **Kingdom Protoctista (protozoa and algae)** – These are often unicellular, or consist of collections of similar cells. They are eukaryotic (possess a membrane-bound nucleus), but are neither fungi, plants nor animals, e.g. *Amoeba*, *Trypanosoma*.
- **Kingdom Fungi (fungi)** – All are eukaryotic and multicellular. They have no roots, stems or leaves and are not photosynthetic (do not possess chlorophyll). The vegetative body, called the mycelium, consists of a mass of fine, multinucleate threads, called hyphae. These have a non-cellulose cell wall. Their mode of nutrition is either saprotrophic or parasitic (see Year 1 Section 5 Unit 1), e.g. *Rhizopus* (mould), *Agaricus* (mushroom).
- **Kingdom Plantae (plants)** – All are multicellular, eukaryotic and photosynthetic (possess chlorophyll). They have cellulose cell walls, e.g. *Brachymenium* (moss), *Pteridium* (fern), *Zea* (maize).
- **Kingdom Animalia (animals)** – All are multicellular, eukaryotic and non-photosynthetic. Almost all are capable of locomotion. They possess nerve tissue for co-ordination, e.g. *Fasciola* (liver fluke), *Achatina*

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(giant African snail), *Valanga* (grasshopper), *Tilapia* (freshwater fish), *Rana* (frog), *Agama* (lizard), *Felis* (leopard).

ACTIVITY 7 Putting organisms into groups

1 Examine the organisms illustrated in Figure 1.25.

2 With the help of the descriptions in the text and Figure 1.24, write down the correct group to which each organism belongs.

3 Give two features that enabled you to decide on the correct group for each organism.

Viruses

Viruses do not fit into the above system of classification. They do not possess a nucleus, cytoplasm or cell membrane. Some can be crystallised like chemicals, which are non-living. They can reproduce, but only inside a living cell. For this reason they can be regarded as living.

Viruses are much smaller than bacteria and can only be seen with an electron microscope. They have a variety of shapes, e.g. rods, spirals, spheres and hexagons. All known viruses cause diseases, e.g. sore throat, yellow fever, poliomyelitis in people; foot and mouth disease in cattle; and mosaic disease in tobacco and cassava. Some viruses are illustrated in Figure 1.26.

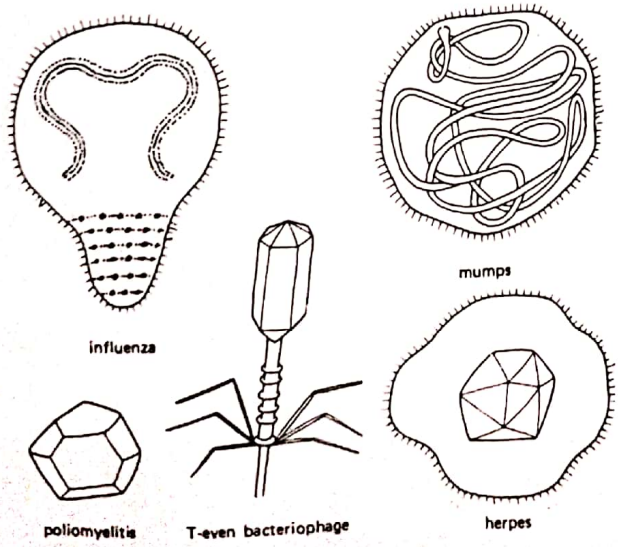


Fig 1.26 Examples of viruses.

Richmond

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 To which of the following kingdoms do bacteria belong?
- **A** Prokaryotae
- **B** Protoctista
- **C** Fungi
- **D** Plantae

2 Which of the following animals does not have a backbone?
- **A** toad
- **B** snail
- **C** tortoise
- **D** snake

3 Which of the following organisms is not an arthropod?
- **A** grasshopper
- **B** lobster
- **C** spider
- **D** earthworm

4 Organisms that can interbreed belong to the:
- **A** breeders level
- **B** species level
- **C** kingdom level
- **D** Protoctista level

5 Each of the following are life processes except:
- **A** reproduction
- **B** excretion
- **C** respiration
- **D** egestion

6 **a)** Explain the terms:
- (i) binomial system
- (ii) key (in classification)
- (iii) species.

b) Distinguish between 'the family' in the level of classification of organisms and 'family' as a social group.

c) List the four groups (classes) into which arthropods are divided. Give one example in each case. On what basis are these organisms classified into groups?

7 Explain why each of the following scientists is said to be important:
- **a)** Aristotle
- **b)** Mendeleev
- **c)** Carolus Linnaeus.

8 Rearrange the following levels of classification of humans in the correct order, starting from kingdom:

Homo, primate, *sapiens*, Mammalia, Chordata.

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9 Record the symbol or symbols as answers to each of the questions about the first 18 elements of the periodic table.

C	N	B	Be	H	Li
Fe	Mg	Ne	Na	Al	He
O	Ar	Cl	S	P	Si

a) Which symbol is not one of the first 18 elements of the periodic table?

b) Name:

(i) a group of two elements in the second short period

(ii) an element that starts the third short period

(iii) two elements within which the second short period falls

(iv) a metalloid in the third short period.

10 **a)** List the five kingdoms of biological classification and give two examples from each.

b) Give reasons why this classification is important.

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9 Record the symbol or symbols as answers to each of the questions about the first 18 elements of the periodic table.

C	N	B	Be	H	Li
Fe	Mg	Ne	Na	Al	He
O	Ar	Cl	S	P	Si

a) Which symbol is not one of the first 18 elements of the periodic table?

b) Name:

(i) a group of two elements in the second short period

(ii) an element that starts the third short period

(iii) two elements within which the second short period falls

(iv) a metalloid in the third short period.

10 **a)** List the five kingdoms of biological classification and give two examples from each.

b) Give reasons why this classification is important.

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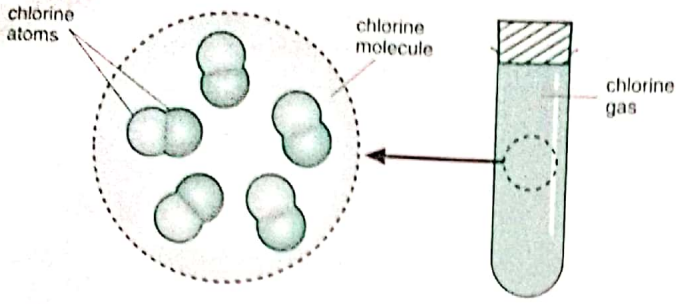


Fig 1.28 Chlorine molecules.

Examining a sample of pure water also in detail would show that the simplest particle that exists separately is a molecule consisting of three atoms (Figure 1.29). Each water molecule is made up of two atoms of hydrogen and one atom of oxygen chemically joined together to form a compound.

A **molecule** consists of two or more atoms of the same or different elements chemically bonded and exists as a stable particle. All molecules of a pure substance are the same. Molecules of different pure substances are different.

A molecule is described as **diatomic** and **triatomic** if they contain two atoms and three atoms respectively. Table 1.9 contains examples of some of the different types of molecules. The number of atoms in one molecule of a substance is called its **atomicity**.

The ion

An **ion** is an electrically charged particle formed from an atom or group of chemically combined atoms by losing or gaining one or more electrons. The ion can be formed from an atom of a metal (e.g. Na^+, Cu^{2+}) or non-metal (Cl^-) or can be a polyatomic ion (SO_4^{2-}, NH_4^+, CO_3^{2-}).

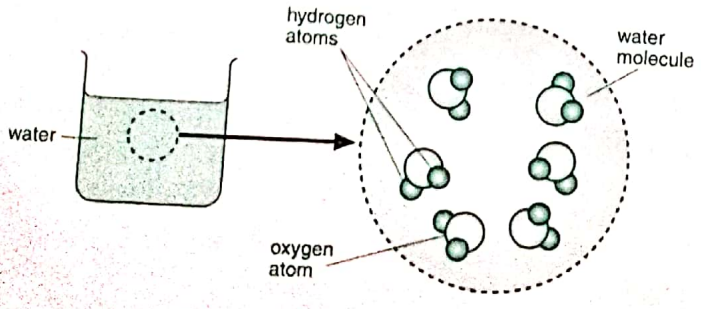


Fig 1.29 Water molecules.

Table 1.9 Examples of some of the different types of molecules

Molecule type	Examples
diatomic	some non-metals at room temperature: oxygen (O_2), chlorine (Cl_2), iodine (I_2) and nitrogen (N_2)
triatomic	some non-metals at room temperature: ozone (O_3)
compound – varied number of atoms	ammonia (NH_3), water (H_2O), sucrose ($C_{12}H_{22}O_{11}$)

A metal readily loses its outermost electron or electrons to form a positive ion or cation. The number of positive charges carried on a cation is equal to the number of electron(s) lost by the metal atom. Examples are given in Table 1.10.

Table 1.10 Some metals and their ions

Parent atom (electronic configuration)	Electrons lost	Name and symbol of ion (electronic configuration)
sodium (2,8,1)	1	sodium ion, Na^+ (2,8)
calcium (2,8,8,2)	2	calcium ion, Ca^{2+} (2,8,8)
aluminium (2,8,3)	3	aluminium ion, Al^{3+} (2,8)

Metal ions carry positive charges because the number of positively charged protons in the nucleus becomes greater than the number of negatively charged electrons surrounding it. For example, in a sodium *atom* there are 11 protons in the nucleus and 11 electrons surrounding it. Loss of one electron to form a sodium *ion* means that there are still 11 protons but now only 10 electrons. There is a net charge of 1^+ (+11 – 10). This charge is written as a superscript at the right of the symbol of the element (Figure 1.30). The ammonium radical, or ion, NH_4^+ also is positively charged.

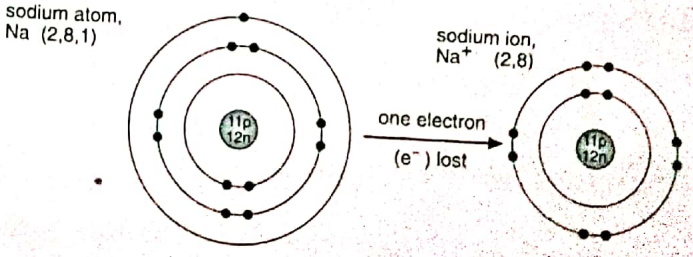


Fig 1.30 Formation of a sodium ion.

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Hydrogen atoms also can lose an electron to form an ion with a one positive charge – H^+.

Some non-metals readily gain one or more electrons into their outermost shell to form a negative ion or **anion**. The number of negative charges an anion carries is equal to the number of electron(s) gained by the non-metal atom. Examples are given in Table 1.11.

Table 1.11 Some non-metals and their ions

Parent atom (electronic configuration)	Electrons gained	Name and symbol of ion (electronic configuration)
chlorine (2,8,7)	1	chloride ion, Cl^- (2,8,8)
oxygen (2,6)	2	oxide ion, O^{2-} (2,8)
nitrogen (2,5)	3	nitride ion, N^{3-} (2,8)

Non-metal ions carry negative charges because the number of negatively charged electrons surrounding the nucleus becomes greater than the number of positively charged protons in it. For example, in a chlorine *atom* there are 17 protons in the nucleus and 17 electrons surrounding it. Gain of one electron to form a chloride *ion* means that there are now 18 electrons but still only 17 protons. There is a net charge of 1^- (+ 17 – 18). This charge is written as a superscript at the right of the symbol of the element (Figure 1.31). Notice that when a non-metal forms an anion the name changes slightly; chlorine forms a chloride ion, Cl^-, oxygen forms an oxide ion, O^{2-} and hydrogen forms a hydride ion, H^-. Several common polyatomic ions exist as negative ions including trioxonitrate(V), NO_3^-, trioxocarbonate(IV), CO_3^{2-} and tetraoxophosphate(V), PO_4^{3-}.

A **compound** is a substance containing two or more atoms of different elements chemically joined together in a fixed ratio.

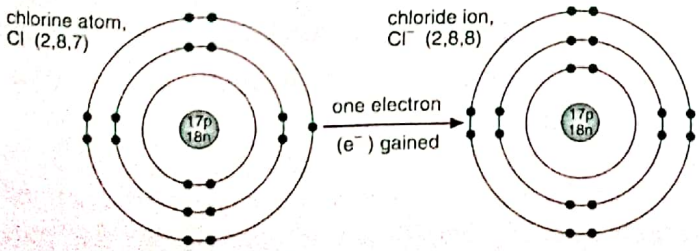


Fig 1.31 Formation of a chloride ion.

Ionic compounds are formed by ions of opposite charge. The ions dissociate when the compound is heated until it melts or dissolves in water to form a solution. Table 1.12 contains examples of ionic compounds and the ions present in them.

Table 1.12 Ionic compounds and the ions they contain

Compound	Ions present
sodium chloride	$Na^+ Cl^-$
sodium hydroxide	$Na^+ OH^-$
ammonium chloride	$NH_4^+ Cl^-$
calcium chloride	$Ca^{2+} 2Cl^-$
calcium trioxocarbonate(IV)	$Ca^{2+} CO_3^{2-}$
magnesium oxide	$Mg^{2+} O^{2-}$
hydrochloric acid	$H^+ Cl^-$

In summary, an ion is an electrically charged particle formed when an atom or molecule loses or gains one or more electrons. Metals form positive ions (cations) and non-metals form negative ions (anions).

Naming of inorganic compounds

There are several ways of naming compounds. The systematic method is discussed in this section. Some of its advantages are:

- it gives one name to one compound
- it gives information about the oxidation state and the number of atoms combining to form the compound.

The **oxidation number** of an atom is the charge the atom carries in its pure state or in its compound.

The naming of substances is determined by their oxidation numbers or oxidation states (combining power).

The following are rules for determining the oxidation states of substances.

1 The oxidation number of:
   a) an element in its uncombined or atomic or molecular form is zero (0)
   b) an ion of a single atom is equal to the charge on the ion
   c) an oxygen atom is –2 except in peroxides, e.g. H_2O_2 and K_2O_2 and superoxides, e.g. KO_2 where it is –1 and –½, respectively
   d) hydrogen is -1 in metal hydrides.

2 The total of the oxidation numbers of all atoms in a neutral formula is zero.
3 The total of the oxidation numbers of all atoms of a polyatomic ion is equal to the charge carried by the radical.

Table 1.13 shows the use of these rules in assigning oxidation numbers to some common substances.

Note from Table 1.13 that:

- some elements (e.g. Cu, Fe) have more than one oxidation state; they are said to show variable oxidation states
- the charge on a substance is written as a right superscript *followed* by its positive or negative sign, e.g. Cu^{2+} and O^{2-} and not Cu^{+2} and O^{-2}
- all metals show a positive oxidation state
- in substances with an oxidation state of +1 or −1, only the sign is written.

Table 1.13 Oxidation numbers of some common substances

Rule	Formula	Oxidation number
1a)	H, H_2	0
	Na	0
	Cl, Cl_2	0
1b)	Cl^-	−1
	O^{2-}	−2
	Cu^+	+1
	Cu^{2+}	+2
	Fe^{2+}	+2
	Fe^{3+}	+3
1c)	H_2O	2(+1) +(−2) = 0
	H_2O_2	2(+1) +2(−1) = 0
1d)	NaH	+1 +1(−1) = 0
2	HCl	+1 − 1 = 0
	H_2SO_4	2 (+1) + (+6) + 4(−2) = 0
	$Al(NO_3)_3$	+3 + 3 [+5 + 3(−2)] = 0
3	CO_3^{2-}	+4 + 3(−2) = −2
	PO_4^{3-}	+5 + 4(−2) = −3
	SO_3^{2-}	+4 + 3(−2) = −2

Binary compounds

These are compounds containing atoms of two different elements only. One of the two elements is more electronegative – it attracts electrons more towards itself than the other element does. A more electronegative element has a negative oxidation state and is to be found nearer to the right hand side of the periodic table.

In naming the binary compound, several rules apply:

1 The suffix '-ide' replaces the last two or three letters in the name of the more electronegative element, e.g. chlorine, oxygen, nitrogen, sulphur and hydrogen become chloride, oxide, nitride, sulphide and hydride, respectively.
2 The modified name of the more electronegative element is written second.
3 The name of the less electronegative element is written first. It is not modified. If the element exhibits only one oxidation state this is not shown. Otherwise, the oxidation state is placed in parentheses in capital Roman numerals immediately after the name of the element.

Old or trivial names are used for some compounds. The International Union of Pure and Applied Chemistry (IUPAC) has developed standards for the naming of chemical elements and their compounds. In some cases, *either* the systematic IUPAC name or the trivial name can be used, e.g. water, carbon dioxide.

There are more examples in Appendix IV.

Examples of names of binary compounds are shown in Table 1.14.

Table 1.14 Names of common binary compounds

Combining elements	Name of compound
potassium + iodine	potassium iodide
hydrogen + oxygen	water
iron + sulphur	iron(II) sulphide or iron(III) sulphide
aluminium + chlorine	aluminium chloride
sulphur + oxygen	sulphur(IV) oxide or sulphur(VI) oxide
magnesium + hydrogen	magnesium hydride

Ions

Simple ions are named using the following rules.

1 For *cations* of elements with fixed (only one) oxidation state, the name of the element is written plus the word ion; the oxidation state is not shown (Table 1.15).
2 For *cations* of elements with variable oxidation states, the oxidation state is written in Roman capital numerals, in parentheses, immediately after the name of the element.

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3 *Anions* take the suffix '-ide' as does the more electronegative component of a binary compound, plus the word ion.

Table 1.15 Names of simple cations

Symbol Formula	Name
Zn^{2+}	zinc ion
H^+	hydrogen ion
Cu^+	copper(I) ion
Cu^{2+}	copper(II) ion
Fe^{2+}	iron(II) ion
Fe^{3+}	iron(III) ion
Pb^{2+}	lead(II) ion
NH^{4+}	ammonium ion

Oxoanions are radicals or polyatomic ions in which oxygen atom(s) are bonded to a central atom. Names are based on the oxidation number of the central atom and the number of oxygen atoms bonded to it.

1 The suffix '-ate' replaces the last two or three letters in the name of the central atom.
2 The oxidation number of the central atom is given in Roman capital numerals, in parentheses, after its name.
3 The number of oxygen atoms is placed *before* the name of the central atom as 'dioxo', 'trioxo', 'tetraoxo', 'pentaoxo', 'hexaoxo', 'heptaoxo', etc. for two, three, four, five, six and seven oxygen atoms, respectively. There is no prefix 'mono' if the number of oxygen atoms is only one.
4 The word ion is added to the name.

Examples of names of oxoanions are shown in Table 1.16.

Table 1.16 Oxoanions and their systematic names

Formula	Name
CO_3^{2-}	trioxocarbonate(IV) ion
NO_3^-	trioxonitrate(V) ion
SO_4^{2-}	tetraoxosulphate(VI) ion
ClO^-	oxochlorate(I) ion
ClO_3^-	trioxochlorate(V) ion
HCO_3^-	hydrogentrioxocarbonate(IV) ion
OH^-	hydroxide ion
MnO_4^-	tetraoxomanganate(VII) ion

Oxoacids are compounds containing one or more hydrogen atom(s) and an oxoanion. They are named in the same way as oxoanions but the word 'acid' replaces the word 'ion' in the name of the oxoanion. Examples are trioxonitrate(V) acid, HNO_3, tetraoxosulphate(VI) acid, H_2SO_4 and oxochlorate(I) acid, HClO.

Bases may be conveniently divided into oxides and hydroxides. Oxides are named in the same way as binary compounds. A hydroxide is composed of a cation and a hydroxide ion, OH^-. Hydroxides also are named in the same way as binary compounds. Examples are sodium hydroxide, NaOH, calcium hydroxide, $Ca(OH)_2$ and iron(II) hydroxide, $Fe(OH)_2$.

Salts are formed when a metal (or ammonium) cation replaces the hydrogen(s) of an acid. Salts may be divided into binary salts and oxoacid salts. The name of a binary salt is a combination of the names of the cation and the anion. Examples are ammonium chloride, NH_4Cl, copper(II) chloride, $CuCl_2$ and iron(II) sulphide, FeS. **Oxoacid salts** are named by first writing the cation, followed by its oxidation number if it is variable. The name of the oxoanion is then added.

Examples of names of oxoacid salts are shown in Table 1.17.

Table 1.17 Names of oxoacid salts

Formula	Name
$CaCO_3$	calcium trioxocarbonate(IV)
$MgSO_4$	magnesium tetraoxosulphate(VI)
$CuSO_4$	copper(II) tetraoxosulphate(VI)
$Pb(NO_3)_2$	lead(II) trioxonitrate(V)
$NaHSO_4$	sodium hydrogentetraoxosulphate(VI)

Chemical bonds

A **chemical bond** is a force that holds ions, molecules or atoms together. Bond formation involves gain, loss or sharing of outer shell electrons of atoms. A bond is formed so that each atom acquires a stable electronic configuration similar to that of a noble gas.

A noble gas has a fully filled outermost shell containing two or eight electrons. Examples are helium (2), neon (2,8) and argon (2,8,8). An atom has been found to be stable when it has an inert gas electron structure of two or eight electrons in the outermost shell.

An atom achieves a stable electronic configuration in one of the following ways:

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- Metal atoms with one, two or three electrons in the outermost shell lose the electron(s) to form positively charged ions or cations.
- Non-metal atoms with five, six or seven electrons in the outermost shell gain three, two and one electron(s), respectively, to form negatively charged ions or anions.
- Two non-metallic elements with four to seven outer electrons may share electrons with each other. An example is carbon (four) and oxygen (six) in carbon dioxide.

Ionic compounds

Ionic compounds are formed by the attraction of positive and negative ions.

Forces related to fixed positive and negative charges are referred to as electrostatic. An electrostatic force of attraction between the positive and negative ions provides the binding force that holds the ions chemically together. The electrostatic binding force between ions in an ionic compound is called an **ionic bond** or **electrovalent bond.**

During a reaction to form an ionic compound the electronic configurations of the atoms change. Metal atoms lose their outermost electron(s), forming positive ions. Non-metal atoms gain electron(s) to fill their outermost electron shell, forming negative ions. The electrostatic force of attraction between the oppositely charged ions holds the ions together. For example, when a sodium element is placed in chlorine gas, a reaction takes place resulting in the formation of the ionic compound, sodium chloride. The formation could be written as:

$$Na - e^- \rightarrow Na^+$$
$$\tfrac{1}{2}Cl_2 + e^- \rightarrow Cl^-$$

The overall reaction equation is:

$$Na + \tfrac{1}{2}Cl_2 \rightarrow Na^+Cl^- \text{ or } NaCl$$

Note that the positive charge and the negative charge cancel out and therefore the compound carries no net charge. In all ionic compounds, the number of positive charges equals the number of negative charges. The charges on the ions are not usually shown in the formula of the compound unless it is necessary to explain something. Note also that half a molecule of chlorine is equivalent to one atom of chlorine.

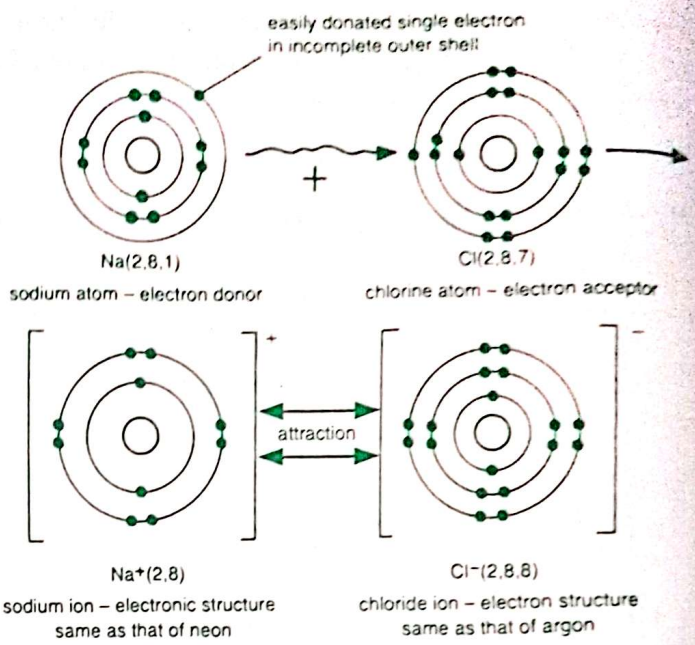


Fig 1.32 Ionic bonding in sodium chloride.

The formation of sodium chloride is illustrated in Figure 1.32.

Table 1.18 lists examples of ionic compounds containing polyatomic ions. Note that some ionic compounds, for example ammonium tetraoxosulphate(VI), are formed *entirely* from polyatomic ions.

- Negatively charged polyatomic ions combine with positive hydrogen ions to form acids and with positive metal ions to form hydroxides and salts.
- Positively charged polyatomic ions combine with negative ions to form hydroxides and salts.

Table 1.18 Ionic compounds containing polyatomic ions

Compound formula	Ions present
HNO_3 (acid)	H^+ NO_3^-
$CuSO_4$ (salt)	Cu^{2+} SO_4^{2-}
NaOH (hydroxide)	Na^+ OH^-
$MgCO_3$ (salt)	Mg^{2+} CO_3^{2-}
$(NH_4)_2SO_4$ (salt)	$2NH_4^+$ SO_4^{2-}

Covalent compounds

A **covalent compound** is formed when two or more atoms donate and share electrons such that each atom acquires a noble gas electronic structure. The **covalent bond** that holds the two atoms together is the electrostatic attraction between the negative charge of the shared electrons and the positive charge of the protons in the nuclei of the two atoms.

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The pair of electrons shared is referred to as the shared pair; it belongs to both of the atoms. In simple covalent bonding, each of the two combining atoms contributes one electron to the bond; thus, the bond consists of two electrons shared between the two atoms.

A covalent bond formed between two atoms is sometimes shown as a short line drawn between the symbols of the atoms: H–H and Cl–Cl. In an oxygen molecule, O_2, each atom donates two electrons to form two covalent bonds. This is shown as two lines, O=O. Where three bonds exist between atoms, such as in a nitrogen molecule, N_2, they are shown as three lines N≡N. These bonds are referred to as **single**, **double** and **triple** covalent bonds, respectively.

Figures 1.33 and 1.34 show how some covalent compounds are formed (note that only the outermost shell is shown). Pairs of outermost shell electrons that are not used in a covalent bond are known as **lone pairs** of electrons. For example, each chlorine atom in the chlorine molecule contains three lone pairs of electrons (Figure 1.33a). How many lone pairs does water have (Figure 1.33b)? Even number of electrons on an atom is the source of lone pairs. Odd number of electrons provides unpaired electrons. For example, each unstable or isolated chlorine atom has one unpaired electron (Figure 1.33a).

Properties of ionic and covalent compounds

Some of the main properties of ionic compounds are given and explained in Table 1.19.

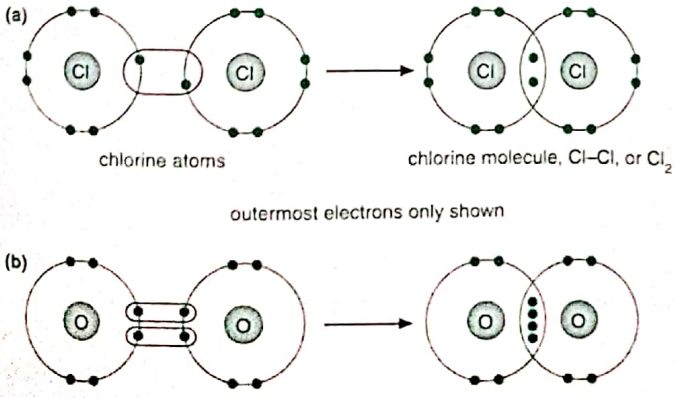


Fig 1.33 Covalent bonding between atoms of the same element in (a) chlorine and (b) oxygen.

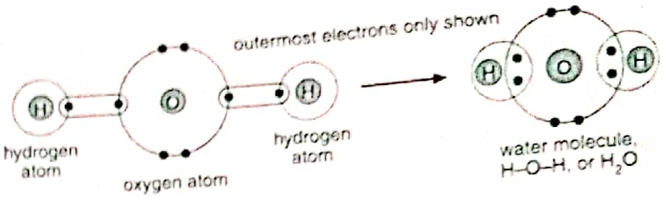


Fig 1.34 Covalent bonding between atoms of different elements – water.

Table 1.19 Main properties of ionic compounds

Properties	Reason(s)
giant crystalline, brittle and hard solids at room temperature	regular arrangement of cations and anions and the strong attraction between the oppositely charged cation and anion result in hard solids
conduct electricity when molten or in aqueous solution; does not conduct electricity in the solid state	on melting or dissolving, ions are free to move and carry an electric current to undergo **electrolysis**; ions are in fixed positions in the solid state
high melting and boiling points; high heats of fusion and vaporisation	ions have strong electrostatic forces of attraction between them; thus lots of energy is needed to separate them
often soluble in water but insoluble in organic solvents	water molecules are charged (polar) solvents; ions in crystals are attracted to the charges to form stable structures with solvent molecules; when an ionic crystal dissolves, the gain in stability is greater than the energy needed to separate the ions

Unlike ionic compounds, which contain aggregates of ions, covalent compounds are made up of molecules; they are molecular substances. Few covalent substances form giant structures in which the covalent bonds are very strong, e.g. diamond and sand. Many molecular substances show the properties listed and explained in Table 1.20.

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Table 1.20 Some properties of covalent compounds

Properties	Reason(s)
some are gases, liquids or soft solids at room temperature	they consist of small molecules with weak attractive forces between them
many do not conduct electricity either in the molten state or aqueous solution	absence of free ions
low boiling and melting points; low heats of fusion and vaporisation	weak inter-molecular forces between the molecules; low energy needed to separate molecules
many are soluble in organic solvents but insoluble in water	the molecular substances dissolve in organic solvents because they have similar covalent structures; do not need high energy to separate the molecules

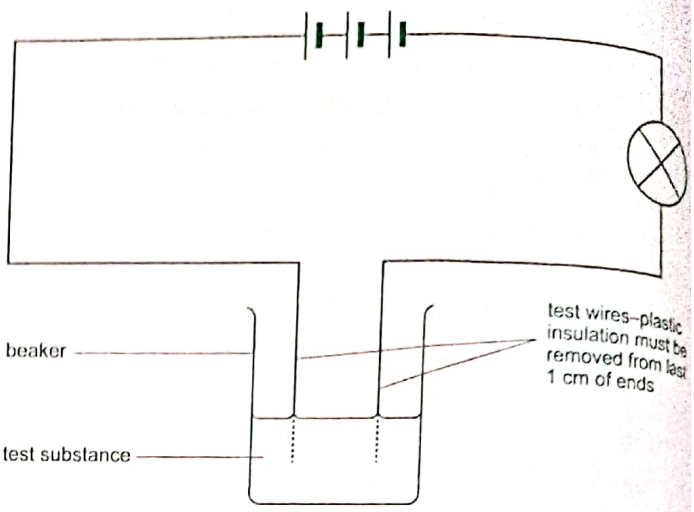


Fig 1.35

ACTIVITY 1 To investigate the physical properties of an ionic and a covalent compound

1 Collect the following from your teacher: sodium chloride, octadecanoic acid (stearic acid), propanone (acetone), four boiling tubes, four 1.5 V cells, a bulb, connecting wires, a thermometer, a large beaker and a small beaker.

2 Place a small amount of sodium chloride in a boiling tube and add water to a depth of about 3 cm. Shake the mixture gently for a few minutes. Record your results. Repeat this using octadecanoic acid in place of the sodium chloride.

3 Place a small amount of sodium chloride in a boiling tube and add propanone to a depth of about 3 cm. Shake the mixture gently for a few minutes. Record your results. Repeat this using octadecanoic acid in place of the sodium chloride.

4 Half fill a large beaker of water and place it on a tripod and gauze to provide a water bath. Gently heat the water. Place octadecanoic acid in a boiling tube to a depth of about 3 cm and insert the thermometer into it. Put the boiling tube into the hot water and carefully stir the octadecanoic acid. Record the temperature at which it melts.

5 Place sodium chloride in a boiling tube to a depth of about 3 cm. Heat the boiling tube directly with a Bunsen burner for several minutes. Record your results.

6 Connect up a circuit like the one shown in Figure 1.35.

7 Place octadecanoic acid in the small beaker to a depth of 1 cm. Heat the beaker gently until the octadecanoic acid melts. When it is molten, insert the test wires, making sure that they do not touch. Watch the solution carefully and explain whether a chemical reaction has taken place.

8 Place some sodium chloride in the bottom of a small beaker and add water to a depth of 3 cm. Stir the mixture for a few minutes. Insert the test wires into the liquid, making sure they do not touch, and record your results.

9 Summarise the properties of sodium chloride and octadecanoic acid for each test. State and explain which is ionic and which is covalent in nature.

Elements, compounds and mixtures

An element, as has been described earlier, is a substance that is made up the same atoms. It may exist as an atom or molecule. A compound is a chemical combination of two or more different atoms in fixed proportion by mass or amount. It may exist as an ionic compound or a covalent substance made up of molecules with covalent bonds. A mixture can be described as a physical mixture of two or more substances which do not react chemically. The natural world is made up of these three types of matter. The differences in their properties help us to identify them. Table 1.21 tabulates the differences and similarities if any.

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Table 1.21 Properties of elements, compounds and mixtures

Elements	Compounds	Mixtures
Made up of one type of atom only.	Made up of two or more different types of atoms chemically combined.	Made up of different types of substances physically combined.
Chemical and physical properties are the same as properties of the element or atoms.	Chemical and physical properties are the properties of the compound as a pure substance, not of the component atoms.	Chemical properties are the separate properties of the pure component substances. Physical properties may be different or intermediate.
Exist as atoms or same atoms joined together as a molecule. It has a symbol.	Atoms are in fixed proportion and exist as covalent molecules or ionic compounds. It has a formula.	Substances are in varied proportion or in fixed limits. It has no symbol or formula.
Cannot be broken down into other simpler atoms except through radioactive decay/reaction.	Can be broken down into component atoms by chemical means only.	Most can be separated by physical means only, e.g. air and petroleum by distillation; salt and water solution by evaporation and crystallisation.
Examples: H_2, O_2, Fe, C, Al.	Examples: H_2O, NaCl, CH_4, $CuSO_4$, FeO, $C_6H_{12}O_6$.	Examples: Air (N_2 – 78%, O_2 – 21%, water vapour – varies, CO_2 – 0.036% and increasing inert gases – 0.091); salt and sugar solutions, petroleum and paints.

ACTIVITY 2 To prepare some mixtures and compounds

Part 1: Mixtures

Solid–solid

Sulphur and iron filings

1 Put small amounts of powdered sulphur and iron filings at separate points on a watching glass. Observe and record their colours.

2 Mix small amounts of the sulphur and iron filings, bit by bit, on the watching glass.

a) Observe and record their colours. Are they different from the colours of the pure components?

b) Describe how you would separate the iron filings from the sulphur.

c) State any other example(s) of a solid–solid mixture and state how you may separate its components.

Sold–liquid

3 a) What is the physical state of water and salt?

b) Explain briefly why water and salt are compounds.

c) Add water to a small amount of salt in a beaker and swirl carefully to dissolve all the salt.

d) State the name(s) of the process(es) by which you would recover the salt and water from the mixture.

Liquid–liquid

4 a) Collect some ethanol from your teacher. State its colour and state.

b) Pour some of the ethanol into a small beaker. Add some water, bit by bit, and observe whether it dissolves, and if it dissolves is the product uniform?

c) Has ethanol got any fixed amount that will dissolve in water?

d) Give two other examples of two liquids that can form a uniform mixture, and one example that will not form a uniform mixture when mixed.

Gas–gas

5 Your teacher will use a clean, dry, large boiling tube or gas jar to demonstrate this experiment.

a) What substance is in the boiling tube? What is its colour?

b) In a fume cupboard, put two or three drops of liquid bromine into the tube and cover it tightly. Allow the set up to stand for some time.

c) Observe what happens to the bromine liquid and explain whether a mixture has been formed.

6 a) What are alloys?

b) Give three common examples of an alloy.

c) Explain whether alloys are mixtures or compounds.

Part 2: Compounds

1 Your teacher will heat a piece of magnesium metal in a Bunsen burner flame. Do not look at the flame directly with your eyes. Why?

2 Allow the product to fall onto a glass plate.

3 Watch carefully and describe the state and nature of the product.

4 a) What two things reacted to give the product?

b) Write a chemical equation to represent the reaction.

5 Is the product different from the reactants?

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ACTIVITY 3 Differences between elements, compounds and mixtures

1 *Work in groups* to classify the following materials into elements, compounds and mixtures: water, salt, iron filings, sea water, sulphur, air and glass.

2 Discuss the differences between elements, compounds and mixtures.

Atomic number, mass number, isotopes and relative atomic mass

Atomic number

The simplest building block of matter is the atom. Atoms are so small that many millions of them would be needed to cover the full stop at the end of this sentence. Some nineteenth- and twentieth-century scientists carried out experiments to find out the structure of the atom or what it is made of. In the main experiment by Rutherford and his students very fast moving charged particles were directed at a very thin sheet of metal. The particles in the atom caused the charged particles to be scattered in different directions or deflected away from their straight path. Rutherford then studied the different ways the charged particles were deflected and this enabled him to deduce the structure of the atom. The structure of the atom is as follows:

- The atom has a nucleus made up neutrons and protons.
- The protons carry a positive charge and the neutrons carry no charge (neutral).
- The electrons carry a negative charge and are in shells or orbits around the nucleus.

The number of protons in an atom is known as its **atomic number** or **proton number.** The symbol of the atomic number is ***Z***. Each atom has its characteristic atomic number, Z.

Since the number of protons in an atom is equal to the number of electrons, the proton number is equal to the number of electrons.

The atomic number, Z, of an element can be written as a *subscript* preceding the chemical symbol for that element. For example, the atomic number of the element hydrogen, H, is one, so this is written as $_{1}H$. Similarly, for helium, the symbol is $_{2}He$, for lithium, $_{3}Li$ and for uranium, $_{92}U$.

Mass number and isotopes

The experiments also showed that electrons of an atom have almost no mass or can be considered as having negligible mass. The mass of the *nucleus* is almost the mass of the whole atom. Thus, the mass of an atom depends on the number of protons and the number of neutrons in the nucleus.

The **mass number** of an atom is equal to the number of protons plus the number of neutrons. The symbol for mass number is ***A***. The number of neutrons in the atom is the **neutron number, *N***. The neutrons and the protons in the nucleus of the atom are referred to as the **nucleons**. The number of nucleons is called the **nucleon number** and this is equal to the mass number.

The mass number of an atom can be calculated by adding the number of neutrons and protons it contains ($A = Z + N$). The mass number can be written as a *superscript* preceding the chemical symbol of the element. For example, the mass number of a hydrogen atom is one, so it is written ^{1}H; the mass number of helium is four, so it is written ^{4}He; the mass number of lithium is seven, so it is written ^{7}Li; and the mass number of uranium is 238, so it is written ^{238}U. The mass number may also be written *after* the name of the element and joined by a hyphen; for example, hydrogen-1, helium-4, lithium-7 and uranium-238.

The mass number and atomic number can be written together, thus for hydrogen we have $^{1}_{1}H$, for helium, $^{4}_{2}He$, for lithium, $^{7}_{3}Li$ and, for uranium, $^{238}_{92}U$.

The word **nuclide** is used for an atom or nucleus with a known or specified number of protons and neutrons, e.g. $^{24}_{11}He$ which has 11 protons and 13 neutrons and $^{24}_{12}Mg$ which has 12 protons and 12 neutrons. The term is often used to characterise the nucleus or the atom with its mass number.

Isotopes

Isotopes are atoms of the same element with a different number of neutrons. Or they are atoms of the same element with different mass numbers. Many elements have two or more isotopes.

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All atoms of the same element have the same atomic number, as they have the same number of protons. **Isotopes also have the same number of electrons but different mass.** The symbols for the nuclides of the three isotopes of hydrogen are $^{1}_{1}H$, $^{2}_{1}H$ and $^{3}_{1}H$ or hydrogen-1, hydrogen-2 and hydrogen-3. Table 1.22 contains information about three isotopes of the element carbon.

Table 1.22 Isotopes of carbon

Isotope	Atomic number (*Z*)	Number of neutrons (*N*)	Mass number (*A*)
carbon-12	6	6	12
carbon-13	6	7	13
carbon-14	6	8	14

The symbols for the nuclides of the three isotopes of carbon are: $^{12}_{6}C$, $^{13}_{6}C$ and $^{14}_{6}C$. They can also be written as carbon-12, carbon-13 and carbon-14, respectively.

ACTIVITY 4 To write down the atomic number, mass number and symbol of isotopes of some different elements

1 Copy and complete the gaps in Table 1.23.

Table 1.23

Isotope	*Z*	*N*	*A*	Number of electrons	Symbol of nuclide
hydrogen-1 hydrogen-2 hydrogen-3	1 1 1	0 1 2	1		$^{1}_{1}H$
oxygen-16 oxygen-17 oxygen-18	8	8			
magnesium-24 magnesium-25 magnesium-26	12	12			
chlorine-35 chlorine-37	17	18			

Relative atomic mass

Atoms of different elements have different masses. Atoms are so small that they cannot be seen by the human eye and cannot be weighed directly. However, their very small masses can be compared. An atom is chosen and all other atoms of the different elements are compared to it. Such masses are called the **relative atomic masses** of the elements.

The atom currently chosen for comparison with all other atoms is the carbon-12 isotope of carbon and the scale of relative atomic masses obtained is called the **carbon-12 scale.**

On the carbon-12 scale, 12 units of mass are equal to the mass of one atom of carbon-12, or one unit of mass is equal to 1/12 of the mass of one atom of carbon-12. This one unit of mass of carbon-12 is called the **atomic mass unit** and is given the symbol u or m_u.

Using the carbon-12 scale, the masses of atoms can be compared to obtain their relative atomic masses. Relative atomic mass has *no* units since it is a comparison of masses in the same units. In summary:

- The relative atomic mass of an atom is the mass of the atom divided by 1/12 of the mass of one atom of carbon-12.
- It can also be considered as the number of times an atom is as heavy as 1/2 of the mass of one atom of carbon-12 or one mass unit, u.

When the relative atomic mass is given with the unit, u, it is called the **atomic mass.** Thus the relative atomic mass of sodium is 23 and its atomic mass is 23 *u*. 23 *u* means 23 times (multiplied by) 1/12 the mass of one carbon-12 atom. The atomic number and relative atomic masses of the elements can be found in the periodic table in Appendix III.

The mole as a unit and formula mass

Substances are made up of tiny particles – atoms, molecules or ions. Individual particles are so small that they cannot be seen by the naked eye; however, collections of millions and millions of particles gathered together *can* be seen by the naked eye.

In everyday life we sometimes use the units 'dozen' or 'gross', meaning a collection of 12 or 144 things, respectively. Scientists, especially chemists, measure the quantity of matter as the amount of substance. It is one of the seven base physical quantities. For the large number of particles in matter or in any amount of substance, the unit is the **mole.** Just as a dozen is a collection of 12 items, a **mole** is a collection of 602 000 000 000 000 000 000 000 particles or

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6.02×10^{23} particles. This number is huge and a constant number called **Avogadro's constant.** Its symbol is L.

$L = 6.02 \times 10^{23}$ particles.

- The unit of measurement for amount of substance (symbol n) is the **mole.** The symbol of the unit is **mol.**
- A mole of any substance contains 6.02×10^{23} particles of that substance. The particles can be atoms, molecules or ions.
- The mass of one mole, or 6.02×10^{23} particles, of any substance is known as its **molar mass** (M). One mole of any substance is represented by its chemical formula.

The molar mass is numerically equal to the relative atomic mass of an atom. Its unit is the gram per mole. For example, the relative atomic mass of magnesium is 24 and, therefore, its molar mass is 24 g mol^{-1}.

The mass of one mole of a molecule or ion is the sum of the relative atomic masses of all the atoms in the formula of the substance. It is also known as the **relative molecular mass** or **formula mass** of the substance. For example, the relative atomic mass of the hydrogen atom, H, is 1. The formula for one molecule of hydrogen is H_2 – it is made up of two hydrogen atoms – therefore the molar mass of hydrogen molecule is $2 \times 1 = 2$ g mol^{-1}. The *relative* molecular mass of the hydrogen molecule is 2 (with no units).

When the formula of a substance and the relative atomic mass of each element in it are known, the molar mass can be calculated. Table 1.24 gives some examples.

Table 1.24 Calculating molar masses

Substance	Formula	Add the relative atomic masses	Molar mass (M)/g mol^{-1}
water	H_2O	$(2 \times 1) + 16 = 2 + 16$	18
sodium hydroxide	NaOH	23 + 16 + 1	40
hydrochloric acid	HCl	1 + 35.5	36.5
common salt	NaCl	23 + 35.5	58.5
sugar	$C_{12}H_{22}O_{11}$	$(12 \times 12) + (22 \times 1) + 11 \times 16) = 144 + 22 + 176$	342

Using sodium hydroxide, NaOH, whose molar mass is 40 g mol^{-1} to illustrate:

- one mole (1 mol) of sodium hydroxide have a mass of 40 g
- two moles (2 mol) of sodium hydroxide have a mass of 80 g
- half a mole (½ mol) of sodium hydroxide has a mass of 20 g
- n moles (n mol) of sodium hydroxide have a mass of $n \times 40$ g (molar mass, M).

The general formula for calculating the mass of any substance is then

$$m = n \times M$$

From this relation, the amount of substance can be found as

$$n = \frac{m}{M}$$

When the mass and molar mass of any substance is known, the amount of substance can be calculated and vice versa.

For example, if we have 80 g of sodium hydroxide, the amount of NaOH is:

$$n(\text{NaOH}) = \frac{80 \text{ g}}{40 \text{ g mol}^{-1}} = 2 \text{ mol}$$

ACTIVITY 5 To calculate some molar masses and amounts of substance

1 Use the relative atomic masses given to find out the mass of:
   a) 1 mol of copper atoms
   b) 1 mol of carbon atoms
   c) 1 mol of carbon dioxide molecules, CO_2
   d) 1/10 mol of nitrogen atoms.

2 Calculate the amount of substance in the following:
   a) 120 g of trioxocarbonate(IV) ion, CO_3
   b) 31.5 g of trioxonitrate(V) acid, HNO_3
   c) 123 g of copper(II) trioxocarbonate(IV), $CuCO_3$.

Relative atomic masses: C = 12, O = 16, N = 14, Cu = 63.

Concentration of solutions

In Junior High School we learnt the terms *solute, solvent* and *solution*. A solution is a homogeneous mixture of two substances, the solute and the solvent. The solvent is

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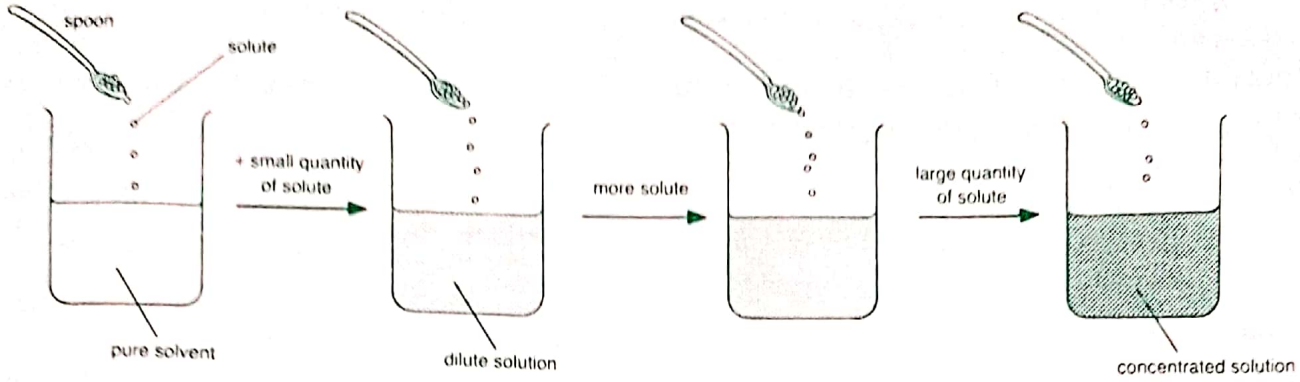


Fig 1.36 Preparing dilute and concentrated solutions.

taken as the component which forms the bigger volume of the solution. Aqueous solutions – solutions in which the solvent is water – are the commonest solutions around us. In this section we shall study the concentration of aqueous solutions.

- The concentration of a solution is defined as the amount of substance (n) divided by the volume of solution (V). The symbol for concentration is c. This statement can be expressed in an equation form as:

$$c = \frac{n\,(\text{mol})}{V\,(\text{dm}^3)}$$

- The unit of concentration is moles per cubic decimetre or mol dm^{-3} or sometimes abbreviated as M.
- The amount of substance in the volume, V dm^3 of solution, can be calculated using another form of the relation:

$$n = c \times V$$

A large amount of solute in a given volume of solution produces a *concentrated* solution. The bigger the amount of solute in a solution, the more concentrated is the solution; the smaller the quantity of solute, the less concentrated or more dilute is the solution. A *dilute* solution is a solution which contains a small amount of solute in the same volume of water compared with the more concentrated solution (see Figure 1.36).

In daily life different concentrations of solutions are needed for different purposes. In preparing a solution exact amounts of solute need to be dissolved in an exact volume of solution before it can be used for the particular purpose. Many medicines are prepared with known concentrations.

Fruit drinks, syrups, disinfectants, insecticides, bleach and many other solutions are diluted to get known concentrations for a particular use in our homes, industry, farms and other places. Chemicals in a school laboratory are prepared and labelled with known concentrations for various uses (Figure 1.37). Knowledge of the concentration of solutions, especially medicines, helps in their administration and use. Many herbal medical preparations sold in markets and lorry parks have unknown concentrations and can therefore be dangerous to use.

Calculating the quantities required in the preparation of solutions

It is useful to practise calculating the various amounts of substance or mass needed to prepare solutions of given concentrations (c) and volume (V). There is no instrument that determines the amount of substance directly; therefore the mass is determined first using the relation $m = n \times M$. Alternatively, if this relation is substituted in the relation used to determine concentration

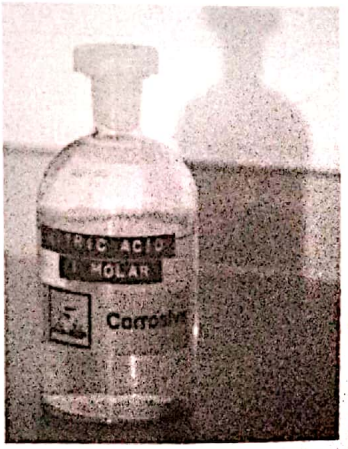


Fig 1.37 Laboratory chemicals of known concentration.

$n = c \times V$, a more useful relation $m = c \times V \times M$ is obtained to calculate the mass directly. This relation enables you to calculate directly the mass, m of the substance with molar mass M, which has to be weighed to prepare V dm^3 of solution of concentration c.

For example, the mass of glucose, $C_6H_{12}O_6$, that has to be weighed to prepare 500 cm^3 of 1.00 mol dm^{-3} of its aqueous solution can be calculated as follows:

Method 1

Volume of solution = 500 cm^3 = 0.500 dm^3
Concentration of solution = 1.00 mol dm^{-3}
Amount of glucose needed, $n = c \times V$
c = 1.00 mol dm^{-3} and V = 500 cm^3 = 0.500 dm^3
Therefore, n (glucose)= 1.00 mol dm^{-3} × 0.500 dm^3 = 0.500 mol
To calculate the mass of glucose the relation $m = n \times M$ is used, giving
m (glucose) = 0.500 mol × 180 g mol^{-1}
= 90 g

Method 2

The mass of glucose can be calculated directly without calculating the amount of substance first by using the relation $m = c \times V \times M$
c = 1.00 mol dm^{-3}, V = 500 cm^3 = 0.500 dm^3 and M = 180 g mol^{-1}
Therefore, m (glucose) = 1.00 mol dm^{-3} × 0.500 dm^3 × 180 g mol^{-1}
= 90 g

ACTIVITY 6 To prepare 1 M solutions of each of sodium hydroxide, sugar and common salt

Caution: Sodium hydroxide is corrosive and causes severe skin burns.

Note: The preparations can be done in groups. Each group should prepare one of the solutions.

1 Get a clean dry beaker, a 250 cm^3 standard volumetric flask, a wash bottle, a funnel, a dropper and a balance (Figure 1.38).
2 Calculate the mass of each solute that has to be weighed to prepare 250 cm^3 of each 1 M solution. The relative atomic masses are: Na = 23, O = 16, H = 1, C = 12, Cl = 35.5. The formula for sugar is $C_{12}H_{22}O_{11}$.
3 Weigh the calculated mass of your solute into the beaker and record it.
4 Transfer *all* the solute from the beaker into the flask as shown in Figure 1.38. Wash the inside of the beaker and funnel well with distiiled water. Shake the flask to mix well.

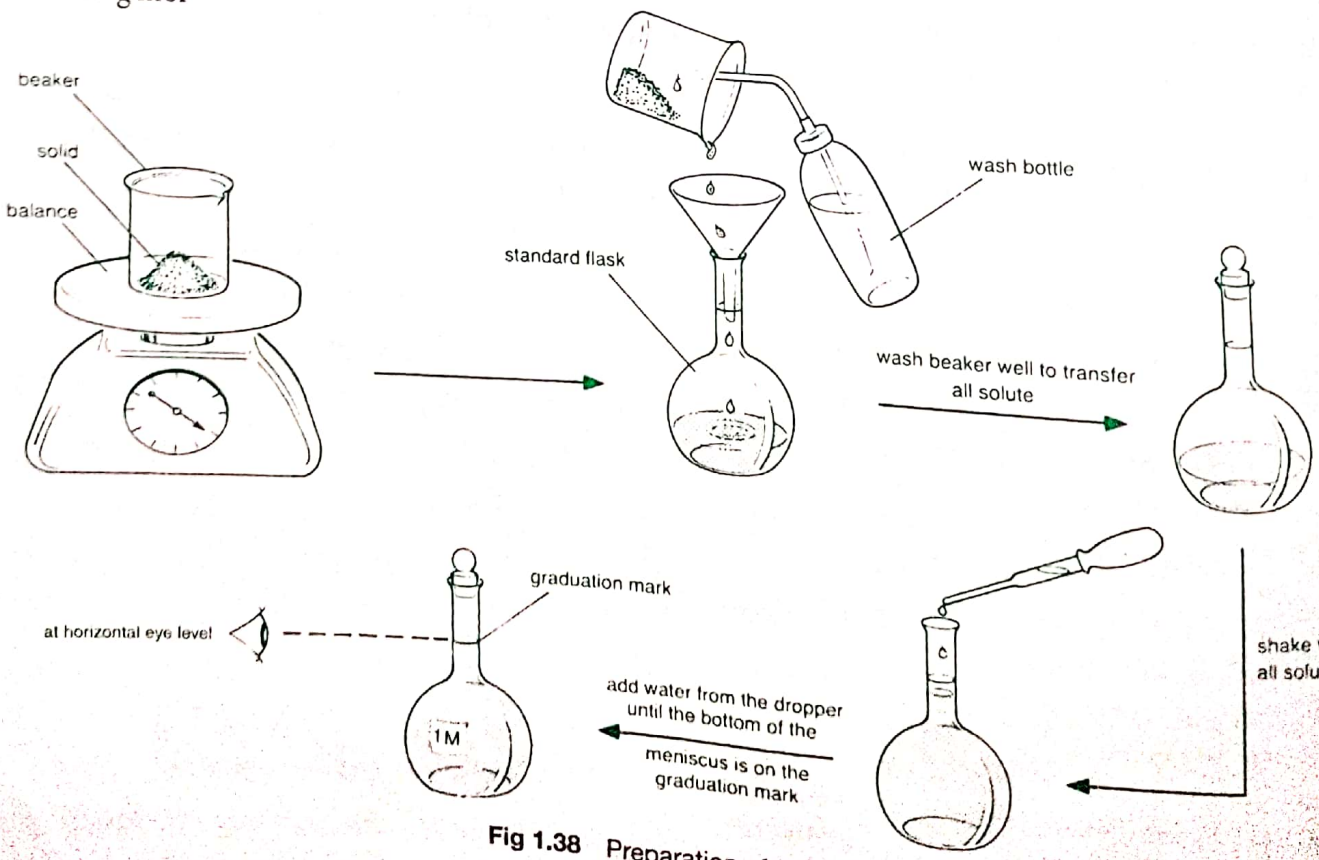


Fig 1.38 Preparation of a 1 M solution.

5 Add more water until the level is near the graduation mark. Top it up to the mark with a dropper. The bottom of the meniscus should be on the horizontal eye level at the mark. Shake the flask well again.

6 Label the flask with the name and concentration of the solution.

7 State one way you can use your prepared solution.

The steps involved in the preparation of a solution of known concentration is summarised as follows:

1 The mass of the substance is calculated.
2 The calculated mass is weighed in a clean dry beaker.
3 The weighed mass is carefully transferred into a standard volumetric flask with distilled water.
4 The beaker and funnel are rinsed well into the flask. The flask is stoppered and shaken well to dissolve all the solute.
5 Distilled water is added up to the point where the liquid level is near the graduated mark on the flask.
6 A teat pipette is used to add distilled water drop wise until the bottom of the meniscus is at the horizontal eye level.
7 The flask is then labelled with the name and concentration of the solution and date of preparation.

Other ways to express concentration

Concentration may be expressed in a similar form using sub-multiples and higher multiples, and as a percentage of solute in solution. Examples include (note that 1 dm^3 is equivalent to 1 l (one litre):

- millimoles per dm^3, millimole dm^{-3} or millimole l^{-1}
- milligrams per dm^3, mg dm^{-3} or mg l^{-1}
- parts per million, ppm and parts per billion, ppb
- percentage, %.

Parts per million (ppm) and parts per billion (ppb) refer to the number of parts by mass or volume of solute in one million (10^6) or one billion (10^9) parts by mass or volume of solution. For example, 20 ppm (W/V) means 20 g of solute in 10^6 cm^3 of solution. Similarly, 300 ppb (V/V) means 300 cm^3 of the solute in 10^9 cm^3 of the solution. The units ppm, ppb, mg l^{-1} and millimole l^{-1} are used to express trace, i.e. extremely small, quantities of solute particles in comparatively large volumes of solution.

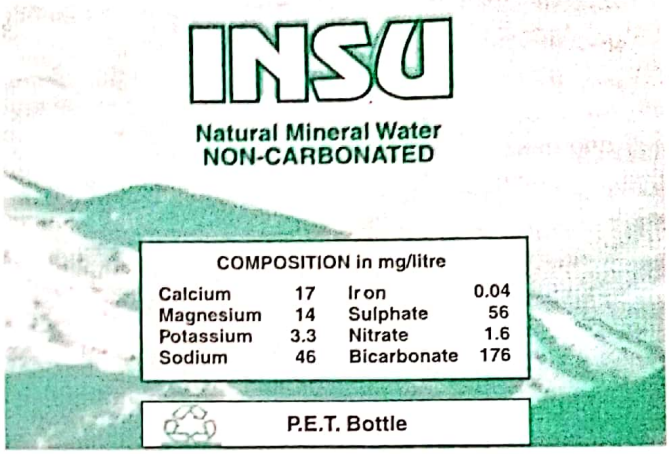


Fig 1.39 Concentrations expressed in mg l^{-1}.

The expression of concentration as a percentage is also common. It indicates the mass, or volume, per 100 g or 100 cm^3 volume of solution. For example, 21 per cent (V/V) of oxygen in air means that there are 21 cm^3 of oxygen in every 100 cm^3 of air. Similarly, 0.034 per cent (V/V) of carbon dioxide gas in air means in every 100 cm^3 of air there is 0.034 cm^3 of carbon dioxide gas.

Percentage concentrations can be converted to ppm, ppb, mg l^{-1}, g dm^3 and other forms, and vice versa. For example, 2 ppm (V/V) of Cl^- in water is:

$$\frac{2\ cm^3}{10^6\ cm^3} \times 100\% = 0.0002\%\ (V/V)$$

Figure 1.39 is an example of a mineral water label showing the mineral concentrations in mg l^{-1}.

Worked example 1

Calculate how many moles of substance are in 68.4 g of sugar.

Solution

Mass of sugar = 68.4 g; molar mass of sugar = 342 g mol^{-1}.

$$\text{Amount of substance, } n = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1})}$$

$$= \frac{68.4\ g}{342\ g\ mol^{-1}}$$

$$= 0.20\ mol$$

Worked example 2

Calculate the mass of sodium trioxocarbonate(IV), Na_2CO_3, to be weighed to prepare 250 cm^3 of a 1 M solution.

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Solution

Volume of solution to be prepared, $V = 250\ cm^3 = 0.250\ dm^3$

Concentration of solution, $c = 1\ M = 1\ mol\ dm^{-3}$

$n\ (Na_2CO_3) = c \times V = 1\ mol\ dm^{-3} \times 0.250\ dm^3 = 0.250\ mol$

mass of $Na_2CO_3 = n \times M$

$n = 0.250\ mol$, $M\ (Na_2CO_3) = 106\ g\ mol^{-1}$

Therefore, $m\ (Na_2CO_3) = 0.250\ mol \times 106\ g\ mol^{-1}$

$= 26.5\ g$

Alternatively, $m\ (Na_2CO_3) = c \times V \times M$

$c = 1\ M = 1\ mol\ dm^{-3}$, $V = 250\ cm^3$, $M = 106\ g\ mol^{-1}$

Therefore, $m\ (Na_2CO_3)$

$= 1\ mol\ dm^{-3} \times 0.250\ dm^3 \times 106\ g\ mol^{-1}$

$= 26.5\ g$

ACTIVITY 7 Concentration of solutions

1 Find the relative molecular mass of ammonia (NH_3). What is the amount of ammonia needed to make 1 dm^3 of a 1 M solution of ammonia?

2 I have 1 dm^3 of a 0.1 M solution of ammonia in water. What mass of ammonia does it contain?

3 A bottle in a laboratory describes a solution as 2 M hydrochloric acid. What mass of hydrogen chloride is present in 1 dm^3 of this solution?

4 Find the formula mass of magnesium tetraoxosulphate(VI) $MgSO_4$. What mass of magnesium tetraoxosulphate(VI) would you need, to make:
   a) 1 dm^3 of 1 M magnesium tetraoxosulphate(VI)?
   b) 1 dm^3 of 0.05 M magnesium tetraoxosulphate(VI)?

Relative atomic masses: N = 14, H = 1, Cl = 35.5, Mg = 24, S = 32, O = 16.

ACTIVITY 8 Collecting labels to examine concentration expressions

1 Collect about four product labels. If the label cannot be removed, copy the contents.

2 Study each label and record the following in vertical columns:
   a) product name
   b) concentration of contents including units, e.g. mg l^{-1}.

3 Convert two different concentrations from any label to different concentration terms.

4 *Work in groups* to discuss the importance of indicating on the label the concentrations of the contents to:
   a) consumers
   b) standards or safety authorities.

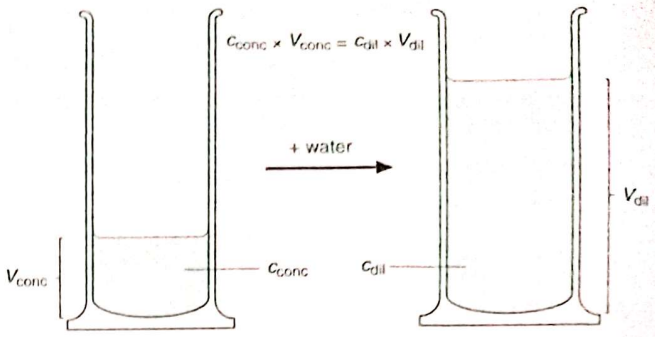


Fig 1.40 The dilution process.

Dilution of solutions

Dilution of a solution takes place when more solvent is added to the solution.

Note that it is only the volume of the solvent which is increased; the amount of substance in the more dilute solution remains the same (Figure 1.40). Therefore:

$$n_{\text{concentrated solution}} = n_{\text{dilute solution}}$$

and, since $n = c \times V$

$$c_{conc} \times V_{conc} = c_{dil} \times V_{dil}, \text{ or}$$

$$c_{conc} \times V_{conc} = c_{dil} \times (V_{conc} + V_{water})$$

This relationship can be used to calculate the volume of water to be added to a more concentrated solution to produce a solution of lower concentration.

The following steps can be followed in diluting a solution to a required volume and concentration:

1 The required volume of the concentrated solution is calculated.
2 The calculated volume of the concentrated solution is measured into a measuring cylinder.
3 Water is added carefully while swirling until the liquid level is near the volume mark of the dilute solution.
4 The solution is topped carefully with water to bring the bottom of the meniscus to the horizontal eye level.

Dilution is a practical process which takes place in everyday human activities. Dilution is carried out in homes in food preparation and in the preparation of herbs and medicines, in food processing, paint production and many other processes in industry. For example, in the home water is added to a concentrated solution of fruit drink and cocoa drink to dilute it to

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a desired taste. Cocoa farmers and gardeners add water to concentrated liquid chemicals (e.g. insecticides and weedicides) to dilute them to desired concentrations to kill the insects without destroying the cocoa tree or flowering plant. Car and furniture sprayers add thinners to lacquers to dilute them. Painters add water to emulsion paints and turpentine to oil paints to dilute them.

Self check

For questions 1 to 18, choose the letter that refers to the correct option.

1 Which of the following statements is/are true about the theory of the particulate nature of matter?
I living things are made up of a complex mixture of pure substances
II matter is made up of atoms
III matter is made up of ions
IV matter is made up of molecules
A I only
B I, II
C II, III, IV
D I, II, III, IV

2 Which of the following statements about chlorine is **not** true?
A the chloride ion has the symbol Cl^+
B chlorine is a gas at room temperature
C two atoms are bonded together in a molecule
D chlorine is a non-metal

3 Which of the following two elements combine to form an ionic compound?
A C and O
B Al and Mg
C H and S
D Cu and O

4 The systematic name for the polyatomic ion PO_4^{3-} is:
A trioxophosphate(IV) ion
B tetraoxophosphate(IV) ion
C tetraoxophosphorous(V) ion
D tetraoxophosphate(V) ion

5 Naphthalene (mothballs) sublimes at room temperature. It is likely that naphthalene exhibits:
A metallic bonding
B ionic bonding
C covalent bonding
D no bonding

6 Concentration of a solution or mixture can be expressed in various physical quantities with units such as:
I mol dm^{-3}
II %
III ppm
IV pH
A I, II, III, IV
B I, II, III
C I, II
D I only

7 The molar mass of tetraoxosulphate(VI) acid, H_2SO_4, is 98 g mol^{-1}. The mass of the acid which will contain 0.62 mol of substance is:
A 58.8 g
B 60.8 g
C 158 g
D 5.8 g

8 You are to dilute the concentrated solution of a fruit drink by following the instruction: 'Add six cups of cold water to one cup of the concentrated solution'. The concentration of the concentrated fruit drink has been reduced by the factor:
A 5
B 6
C 7
D 1/6

9 The chemical formula of the well-known pain killer, paracetamol, is $CH_3CONHC_6H_4OH$. The relative atomic masses of the elements are: C = 12, H = 1, O = 16, N = 14. The relative molecular mass of paracetamol is:
A 150
B 151
C 127
D 1535

10 The World Health Organisation (WHO) standard for the concentration of fluoride ion, F^-, in domestic water supply is 1 ppm (*W/V*). This means the sample of water should contain:
A 1 g of fluoride ions in 10^6 cm^3 water
B 1 mg of fluoride ions in 10^6 cm^3 water
C 1 g of fluoride ions in 10^3 cm^3 water
D 10 g of fluoride ions in 10^6 cm^3 water

11 Which of the following statements on atoms is/are true?
I isotopes of elements have different masses
II atoms of different elements have the same masses
III relative atomic masses of elements are based on the carbon-12 scale
A I, II
B I, III
C I, II, III
D III only

12 The units of amount of substance and molar mass are, respectively:
A mol, no unit
B mol, g mol^{-1}
C mol, gram
D gram, mol

13 The molar mass of potassium hydroxide, KOH, is 56 g mol^{-1}. The amount of substance in 14 g is:
A 4 mol
B 1 mol

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C 0.25 mol
D 0.125 mol

14 A label of a fruit juice indicates that it contains 20 per cent juice. The volume of fruit juice in a 250 ml pack of the product is:

A 200 ml
B 150 ml
C 100 ml
D 50 ml

15 A trace concentration of 0.5 g dm^{-3} of SO_4^{2-} in a water solution is equivalent to:

I 500 ppm
II 0.50 ppb
III 5 ppb
IV 100 ppm

A IV
B I, IV
C I only
D I, III

16 Given 0.200 mol of NaCl, the volume of distilled water needed to prepare a 0.4 M NaCl solution is:

A 0.500 dm^3 **B** 5 dm^3
C 0.0500 dm^3 **D** 200 dm^3

17 30.10×10^{23} atoms of aluminium is equal to:

A 6 mol **B** 5 mol
C 4 mol **D** 3 mol
Avogadro's constant, $L = 6.02 \times 10^{23}$ particles.

18 The number of molecules in 2.5 moles of hydrogen gas is:

A 15.1×10^{23} **B** 6.02×10^{23}
C 2.5×10^{23} **D** 12.0×10^{23}
Avogadro's constant, $L = 6.02 \times 10^{23}$ particles.

19 Here is a list of substances: sodium chloride, water, nitrogen, sodium, hydrogen sulphide, iron(II) sulphide, silicon, chlorine. Which of them consists of:

a) (i) atoms? (ii) molecules? (iii) ions?
b) Which of them will:
(ii) form an ionic compound with sodium
(iii) form a covalent bond with a hydrogen atom
(iv) conduct electricity in its aqueous solution
(v) conduct electricity.
c) State two differences between covalent and ionic compounds.

20 **a)** Name five pieces of apparatus you may use when preparing a solution of a given concentration.
b) You are to prepare 500 cm^3 glucose solution of concentration 1 M. The chemical formula of glucose is $C_6H_{12}O_6$. Calculate the following:
(i) its relative molecular mass and molar mass
(ii) the amount of glucose which will be in solution
(iii) the mass of glucose to be weighed.
c) Outline, in not more than five steps, how you will carry out the preparation.

21 The molar mass of NaOH is 40 g mol^{-1}. 20 g of sodium hydroxide, NaOH, is dissolved completely in distilled water.
a) Copy and complete the following statements:
(i) If the volume of sodium hydroxide solution is made up to 1 dm^3, the concentration will be ... mol dm^{-3} or ... M.
(ii) If the volume of sodium hydroxide solution is made up to 2 dm^3, the concentration will be ... mol dm^{-3} or ... M.
b) When sodium hydroxide dissolves in water, it produces sodium and hydroxide ions. Explain briefly whether there would be more, less or equal numbers of ions in the flasks in a(i) or (ii).
c) What volume of water would have to be added to the volume of the more concentrated solution to obtain the concentration of the less concentrated solution in a(i) and a(ii)?

22 **a)** A solution of soap (formula $C_{17}H_{35}COONa$) is prepared by dissolving 60 g of soap to make 200 cm^3 solution. Calculate the concentration of the soap solution in:
(i) moles per litre
(ii) grams per litre
(iii) percentage (*W/V*).
b) 50 cm^3 of the soap solution prepared was left to dry out. Calculate the mass of solid soap recovered.

23 **a)** Explain the terms 'atomic number' and 'mass number'.
b) You are given the following nuclides: oxygen-16, oxygen-17 and oxygen-18.
(i) Write the symbols which are used to represent them.
(ii) What is the difference between the nuclides?
If the proton number of the oxygen atom is 8, determine the following for each atom:
(iii) number of protons
(iv) number of electrons
(v) number of neutrons
(vi) nucleon number.

24 Magnesium has three isotopes: ^{24}Mg, ^{25}Mg and ^{26}Mg.
a) What is an isotope?
b) Explain whether each isotope will have the same:
(i) molar mass
(ii) number of electrons
(iii) chemical properties.

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5 Cells and cell division

Learning objectives

After studying this unit, you should be able to:

1 describe the structure and function of plant and animal cells
2 explain the process of cell division.

Background information

The cell is the basic unit of life. All living things are made of cells just as most houses are made of bricks or blocks. The cell was discovered by Robert Hooke in 1665, when he observed thin sections of bottle cork under an early light microscope. He observed spaces bounded by walls in the cork like the cells of a honeycomb. Each unit space with the wall around it was named a cell.

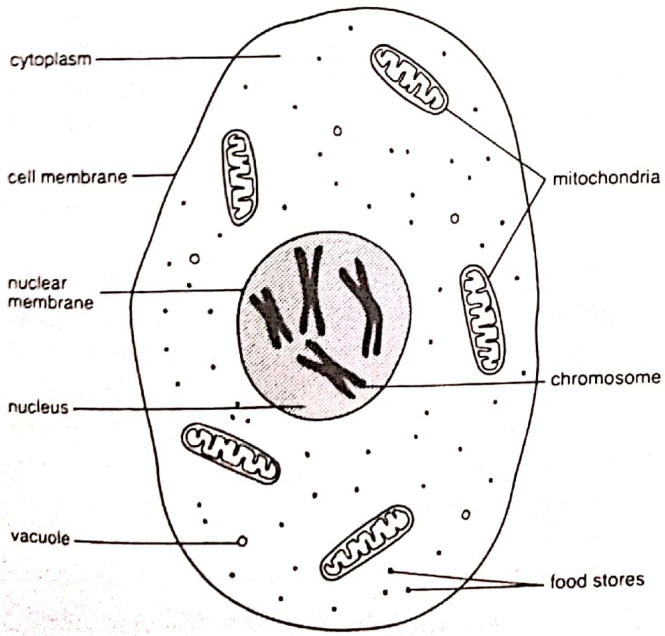


Fig 1.41 A generalised cell.

Further microscope studies showed that all living things are made up of cells. Each cell is capable of carrying out life processes. The detailed internal structure of cells has recently been observed using the electron microscope and advanced staining techniques. Staining brings out the detailed parts of cells using special chemicals. Some living things consist of only a single cell and are called **unicellular** organisms. Others are made up of many cells and are **multicellular**.

The word 'cell' is also used widely in daily life, for example, electric cell, crystal cell, prison cell, telephone cell. In all these usages, the word cell suggests a small, independent unit functioning on its own just like the biological cell.

Structure and functions of the cell

All living cells are made of cytoplasm and are surrounded by a cell membrane (Figure 1.41). Most contain a nucleus.

- **Cell membrane** – a thin flexible structure that surrounds the cell. It is made of fats and protein and is partially permeable.

A **partially permeable membrane** is one through which certain substances can pass and others cannot, depending on the size and nature of the molecules of which the substances are made.

- **Cytoplasm** – a transparent watery fluid which is about 90 per cent water, within which can be found various organelles and chemical substances. It refers to all the cell contents except the nucleus and cell membrane. Chemical reactions take place here.

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- **Organelles** – minute, membrane bound structures in the cytoplasm. Each organelle performs a specific function. The organelles include mitochondria (singular: mitochondrion), endoplasmic reticulum, Golgi bodies (Golgi apparatus), lysosomes, vacuoles and chloroplasts.
- **Nucleus** – a small spherical or ovoid structure in the cytoplasm surrounded by its own membrane – the **nuclear membrane**. The nucleus contains a watery fluid called nucleoplasm in which stainable structures called **chromosomes** are found. Chromosomes contain genes which are responsible for inheritance of characters from parents. There is a small, denser part of the nucleoplasm called the **nucleolus** which manufactures ribosomes. Some cells, such as the red blood cells of mammals, do not possess a nucleus. The nucleus and cytoplasm together form the **protoplasm** of the cell.
- **Mitochondria** – minute spherical or sausage-shaped structures bounded by a double membrane. Mitochondria are the site of energy release from respiration. The number of mitochondria in a cell therefore depends on the cell's energy requirement. For example, they are numerous in muscle cells, the middle piece of sperm cells, the cells at the bases of wings of insects and at the bases of quill feathers on the wings of birds, all of which require much energy for their activities.The mitochondria contain enzymes which take part in the respiration process. The energy released during the process in a mitochondrion is in the form of ATP and is used by the cell for its life activities. The mitochondrion is therefore referred to as the 'power house' of the cell.
- **Endoplasmic reticulum** – a network of minute channels bounded by a membrane. It is found throughout the cytoplasm and connects to the nuclear and cell membranes. Endoplasmic reticulum (ER) is of two types – rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER). Rough endoplasmic reticulum has a rough appearance because it has ribosomes on its outer surface. The ER divides the internal part of the cell into compartments so that chemical reactions occurring in the cell do not interfere with one another. It also provides surfaces which make the chemical reactions follow a regular sequence. Both types serve as transport pathways for materials inside (intracellular transport) and out of the cell (extracellular transport). The rough ER serves as a platform that supports the ribosomes. It also transports the proteins produced by these ribosomes.
- **Golgi bodies** (Golgi apparatus) – these organelles, named after Golgi who discovered them, are stacks of minute flat sacs surrounded by a membrane. They have a cluster of vesicles at their edges. The vesicles are small bodies in the cell containing secretory material. The Golgi bodies are responsible for the production and repair of the cell membrane. They also synthesise complex carbohydrates and are involved in packaging and secretion of proteins and complex carbohydrates. They are numerous in actively secreting cells such as cells of salivary glands.
- **Lysosomes** – small, dark, spherical, fluid-filled structures bounded by a single membrane. They are more abundant in animal cells than plant cells. They contain enzymes involved in digestive breakdown of materials in the cell. Their enzymes are also involved in defending the cell against attack by bacteria, viruses and toxic substances. Enzymes produced by lysosomes destroy old and worn out cells including themselves. Because a lysosome destroys itself too, it is popularly called the 'suicide bag' of the cell.
- **Vacuoles** – fluid-filled spaces in the cytoplasm bounded by a single membrane. Plant cells have large permanent vacuoles occupying up to 80 per cent of the cell volume, which are bounded by a membrane called the tonoplast. The fluid in plant cell vacuoles is called cell sap, a solution containing a mixture of salts, sugars, gases and waste materials. Animal cells contain smaller temporary vacuoles. Functions of vacuoles include the following:
  - They are used for storage of food, water and dissolved substances in most cells.
  - When the large permanent vacuole in plant cells becomes fully filled with cell sap, it pushes against the cell wall, giving the cell shape and firmness.
  - Unicellular protocists, such as *Amoeba*, *Euglena* and *Paramecium*, contain specialised vacuoles called contractile vacuoles, which expel excess water (osmoregulation) and waste metabolic products (excretion) from the cell.
- **Chloroplasts** – large, egg-shaped or disc-shaped organelles bounded by a double membrane. They are found only in the green parts of plants. They contain

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the green pigment, chlorophyll, which absorbs energy in sunlight for photosynthesis.

Other structures in cells

- **Ribosomes** – minute structures found in large numbers in cells. Some are free in the cytoplasm, while others are bound to the outer surface of the rough ER. They are composed of **ribonucleic acid (RNA)** and protein. They are the site of protein synthesis in the cell.
- **Centrioles** – small, rod-like structures found in pairs near the nuclear membrane of most animal cells. Each pair lies close together with their long axes at right angles to each other. They separate and move to opposite poles at the early stages of cell division and are believed to be responsible for the formation of spindle fibres.
- **Cell wall** – a structure surrounding the cell membrane, possessed by bacteria, fungi and plants. It is made up of various substances, e.g. fats and protein (in bacteria), chitin (in fungi) and cellulose (in higher plants). In general, it forms a permeable framework which protects and supports the cell contents.

The detailed structures described so far cannot be seen under the light microscope. Such details can only be seen using a more powerful microscope called the electron microscope and are referred to as the ultrastructure of the cell (Figure 1.42).

ACTIVITY 1 Studying electron micrographs of plant and animal cells

1 Carefully study the plant and animal cells in Figure 1.42.
2 Critically examine the electron micrographs of plant and animal cells in Figure 1.43.
3 Using Figure 1.42 as a guide, identify the organelles in the electron micrographs.
4 Which structures in Figure 1.42 are not visible in the electron micrographs?
5 Draw the electron micrographs and label the following:
a) in each cell – nucleus, mitochondrion, endoplasmic reticulum, Golgi body, ribosome.
b) in plant cell only – chloroplast, vacuole, cell wall.

Plant and animal cells

Figure 1.42 illustrates plant and animal cells. Both plant and animal cells have a nucleus, cytoplasm and cell membrane in common. Both contain mitochondria, ER and ribosomes. The differences between plant and animal cells are summarised in Table 1.25.

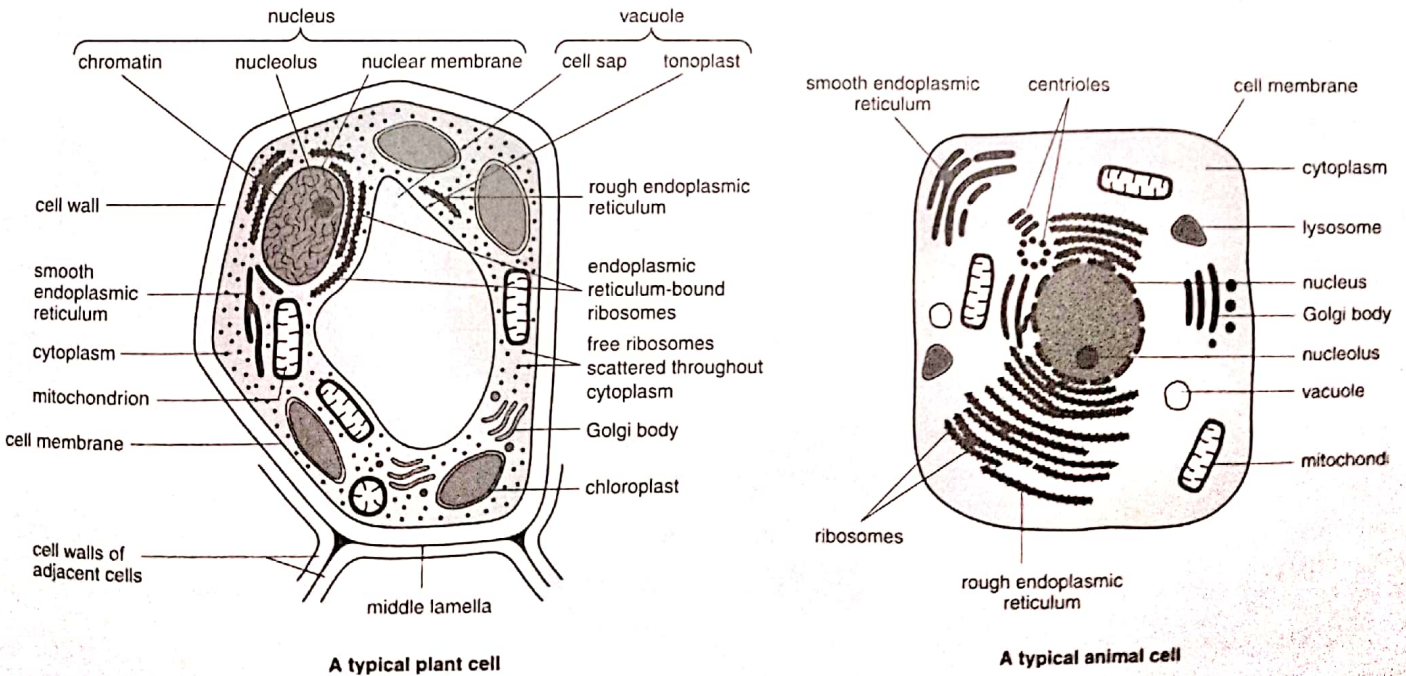


Fig 1.42 The ultrastructure of a plant and an animal cell.

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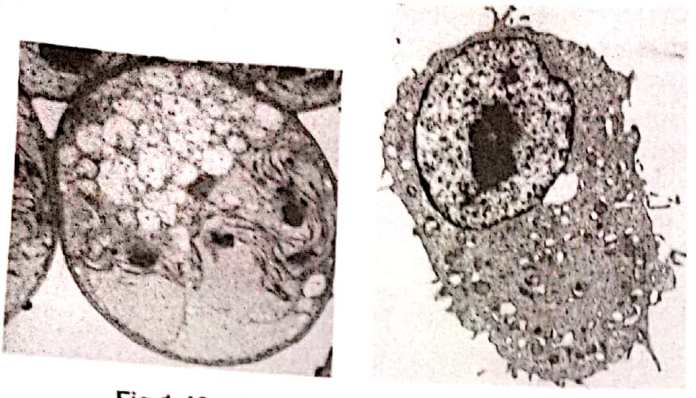


Fig 1.43 Electron micrographs of a plant cell (left) and an animal cell (right).

Table 1.25 Differences between plant and animal cells

Plant cells	Animal cells
cellulose cell wall outside the cell membrane	no cellulose cell wall outside the cell membrane
definite shapes	no definite shape; assume various shapes depending on position in the body
contain large permanent vacuoles	contain small temporary vacuoles
many possess chloroplasts containing chlorophyll	no chloroplasts, therefore no chlorophyll
store starch as carbohydrate food reserve	store glycogen as carbohydrate food reserve

Examples of plant and animal cells

Cells in the bodies of plants and animals differ in size, shape and function. Figure 1.44 illustrates some different types of plant and animal cells. Each cell is specialised for a specific function. For example, in plants root tip cells have the ability to divide and give rise to different tissues. Leaf epidermis cells are transparent and allow light to enter the leaf and reach the photosynthetic tissues below them. Palisade mesophyll cells possess chloroplasts containing chlorophyll, which enables them to act as a photosynthetic tissue. In animals nerve

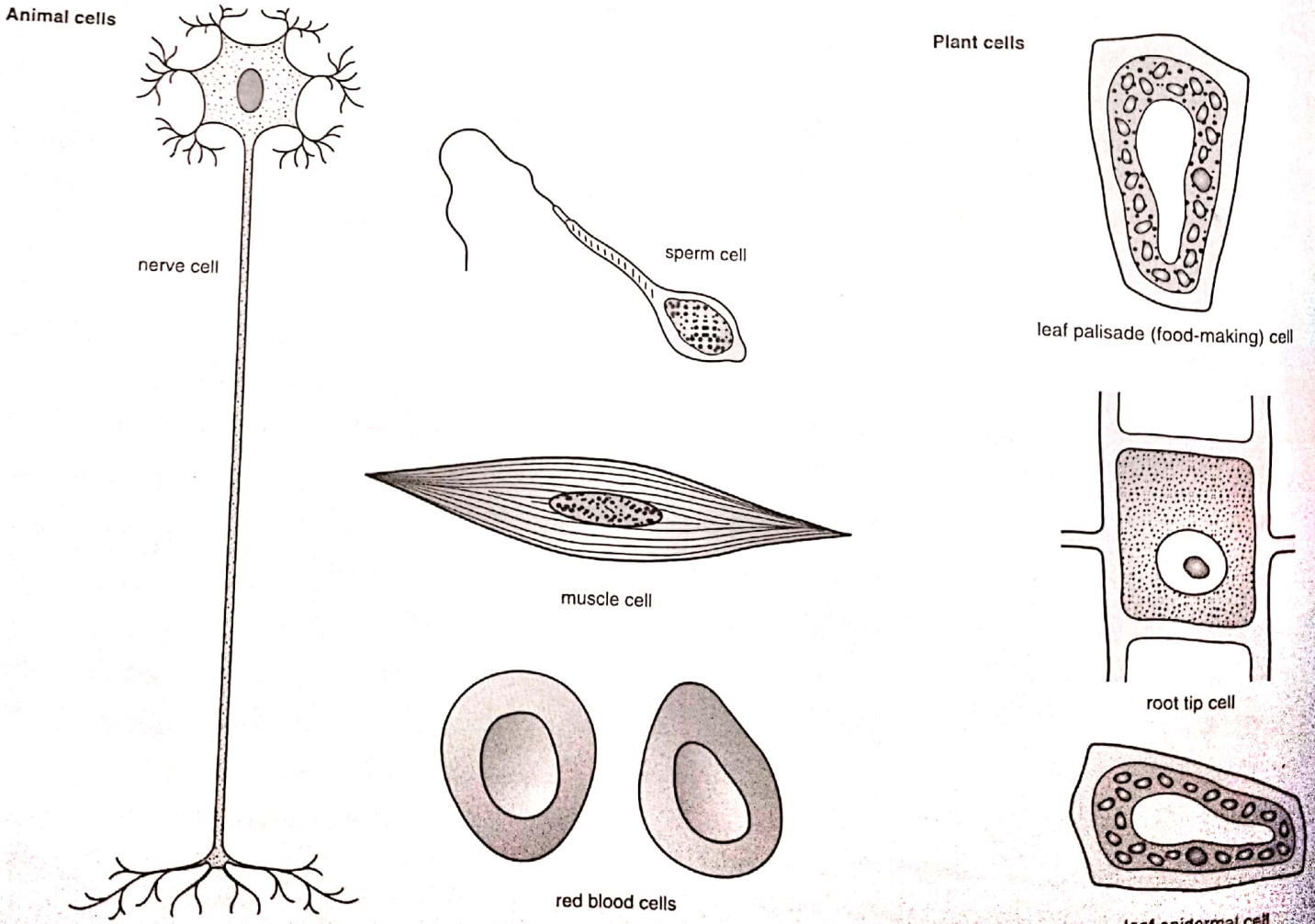


Fig 1.44 Examples of specialised cells.

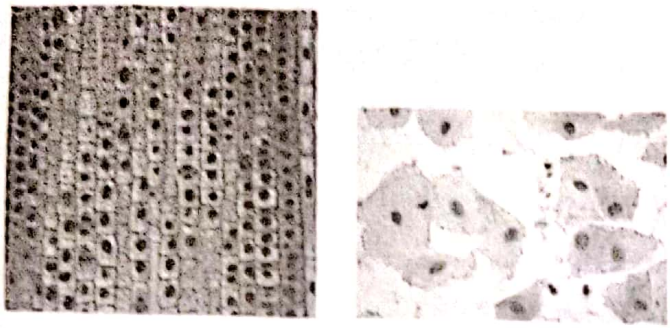


Fig 1.45 (a) onion epidermal cells (b) cheek epithelial cells.

cells are long and thin to enable them to transmit nerve impulses from one part of the body to another. A sperm cell has a long tail which is used to swim to the egg to fertilise it. Red blood cells have the ability to carry oxygen to other body cells via the bloodstream. Muscle cells have the ability to contract.

ACTIVITY 2 Observing cells

1. Your teacher will provide you with prepared slides of different plant and animal cells. These may include onion epidermis cells, leaf palisade cells, human cheek cells, red blood cells, nerve cells and sperm cells.
2. Observe the slides under low power and then high power of your microscope.
3. Draw and label a few cells from each slide, using Figures 1.44 and 1.45 as a guide.
4. Compare the plant epidermal cells with the animal epithelial cells.
5. Compare the cheek cells with the red blood cells.
6. *Work in groups* to discuss the functions of the different cell organelles you have observed.

Levels of organisation of cells in living organisms

Groups of cells that are specialised to perform the same function are called a **tissue**. Table 1.26 gives examples of tissues and their functions.

A **tissue** is a group of specialised similar cells that perform the same function.

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Table 1.26 Examples of plant and animal tissues

Name of tissue	Cells forming tissue	Main function
in plants		
photosynthetic tissue	palisade mesophyll cells	produces food
strengthening tissue	sclerenchyma cells of the pericycle	provides support
epidermal tissue	epidermal cells	covers the plant surface
vascular tissue	xylem vessels, phloem sieve tube elements	transports water, transports organic food
in animals		
blood tissue	red blood cells	carries oxygen around the body and removes carbon dioxide and other waste material from cells
skeletal tissue	osteocytes	provides support
nerve tissue	nerve cells (neurones)	conducts and co-ordinates nerve impulses
muscle tissue	muscle cells	contracts to bring about movement

Groups of different tissues working together are called an **organ**. Some organs perform only one function while others perform two or more functions. Examples of organs and their functions are given in Table 1.27.

An **organ** is a group of different tissues which perform the same function or functions.

Two or more organs working together to perform a specific function form an **organ system**. Table 1.28 gives examples of organ systems and their functions.

An **organ system** consists of two or more organs working together to perform a specific function.

Organ systems are co-ordinated or work together in such a way that a living organism is able to carry out all life processes and exist on its own. Thus, there are five levels of cell organisation in plants and animals:

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Table 1.27 Examples of organs and their main functions

Name of organ	Names of tissues forming organ	Main functions
in plants		
root	root hairs, piliferous layer, cortex, endodermis, pericycle, xylem and phloem	absorbs water and mineral salts from soil and supports the plant
stem	epidermis, collenchyma, parenchyma, vascular bundles	transports water and mineral salts, supports the leaves, flowers and fruit
leaf	epidermis, palisade mesophyll, spongy mesophyll, vascular bundles	makes food, transpires, exchanges gases
in animals		
heart	papillary muscles, cardiac muscles	pumps food and oxygen around the body
kidneys	cortex, medulla	excretes waste metabolic substances, regulates water levels

cells → tissues → organs → organ systems → organism
(arrow means 'form')

ACTIVITY 3 Looking at tissues and organs

1 Examine prepared slides of animal and plant organs under the light microscope.

2 Identify the different tissues.

Cell division

The critical steps in reproduction occur at the microscopic level of the cell. Cellular reproduction enables a parent cell to accurately distribute both genes and cell components to its daughter cells in a process called cell division.

Cell division is therefore the process by which cellular material is divided between two new daughter

Table 1.28 Organ systems and their functions

Name of system	Main organs	Functions
in plants		
root system	roots and their branches	absorbs water and mineral salts, supports the plant
shoot system	stems, leaves, buds, flowers, fruits	makes food, transports organic food, water and mineral salts, reproduces
in animals		
digestive system	stomach, intestines, liver, pancreas	digests and absorbs food
circulatory system	heart, arteries, veins, capillaries	carries food and oxygen round the body
sensory system	eyes, skin, nose, ears, tongue	detects stimuli

cells. In unicellular organisms it increases the number of individuals in the population. In multicellular organisms it is the means by which the organism grows, starting from one single cell.

In prokaryotes cell division occurs via binary fission which means 'splitting in two'. In eukaryotes cell division occurs in two ways:

- mitotic division (**mitosis**)
- meiotic division (**meiosis**).

Mitosis takes place during the growth of an organism. It can be found in all parts that are capable of growth, repair, differentiation and rejuvenation. It occurs in both the germ (sex) cells and somatic (body) cells. In plants it takes place at the tip of growing regions, such as the root of a seedling. In mammals it takes place in the root hair cells, roots of nails, malpighian layer of the skin, bone marrow, lymph nodes and an injured area.

In meiosis the daughter cells finish up with half the total number of chromosomes present in the parent cell. It takes place in the formation of gametes (sex cells). In mammals it is observed in the testes and ovaries. In plants it is observed in the anther and ovaries of flowers.

Mitosis

Mitosis is the division of a cell to produce two identical cells with the same number of chromosomes and characteristics as those of the parent cell. Mitosis occurs

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in one phase only which involves five stages. These are interphase, prophase, metaphase, anaphase and telophase. Two daughter cells are produced which are diploid.

Meiosis

Meiosis is a type of cell division in which a diploid cell undergoes two successive divisions forming four identical haploid cells. Meiosis occurs in two phases each of which involves five stages (though only four main stages are noticeable in the second phase). Four daughter cells are produced which are haploid.

Table 1.29 and Figure 1.46 compare these two types of cell division.

Table 1.29 Comparison of mitosis and meiosis

Mitosis	Meiosis
takes place in somatic cells or body cells	takes place in germ cells or sex cells or reproductive cells
produces two diploid cells identical to the parent cell	produces four haploid cells which are unlike the original cell
occurs in one phase only	occurs in two phases
no pairing up of chromosomes	pairing up of homologous chromosomes
no exchange of genes	exchange of genes
chromosome number is maintained	chromosome number is halved
no crossing over	crossing over occurs

Significance of mitosis

1 It takes place during growth of organisms. For example, in the development of a fertilised egg (zygote).
2 It is significant in the repair of worn out tissues.
3 It is the basis of asexual reproduction.
4 It ensures the constancy of the chromosome number (i.e. diploid condition) in organisms from generation to generation.

Significance of meiosis

Meiosis is significant in the formation of haploid gametes that brings about continuity of species and variation.

Dolly the sheep

Because mitosis produces genetically identical cells, these offspring are genetically identical to their parents. They are called **clones.**

Early in 1997 Dr Ian Wilmut and associates of the Roslin Institute in Edinburgh, Scotland cloned a sheep using a nucleus taken from adult tissue. This type of cloning is the process of artificially creating a clone – a new individual that is genetically identical to an existing individual.

Self check

For questions 1 to 7, choose the letter that refers to the correct option.

1 Who discovered the cells of living organisms?
- **A** Robert Brown
- **B** Robert Hooke
- **C** Robert Koch
- **D** Louis Pasteur

2 A partially permeable membrane can best be described as one through which:
- **A** no substance can pass
- **B** any substance can pass
- **C** only certain substances can pass
- **D** only water can pass

3 In which of the following structures is cellulose found?
- **A** cell wall
- **B** cell membrane
- **C** chloroplast
- **D** mitochondrion

4 Which one of the following is an organ?
- **A** bone
- **B** epidermal cells
- **C** kidney
- **D** palisade mesophyll cells

5 Which of the following sequences of the organisation of cells in plants and animals is correct?
- **A** organs → tissues → cells → organ system
- **B** tissues → organs → cells → organ system
- **C** cells → tissues → organ systems → organ
- **D** cells → tissues → organs → organ systems

6 In mitosis the number of chromosomes in each cell:
- **A** is doubled
- **B** is halved
- **C** remains the same
- **D** varies

7 In meiosis the number of chromosomes in each cell:
- **A** is doubled
- **B** is halved
- **C** remains the same
- **D** varies

8 Describe with diagrams the processes of:
- **a)** mitosis
- **b)** meiosis.

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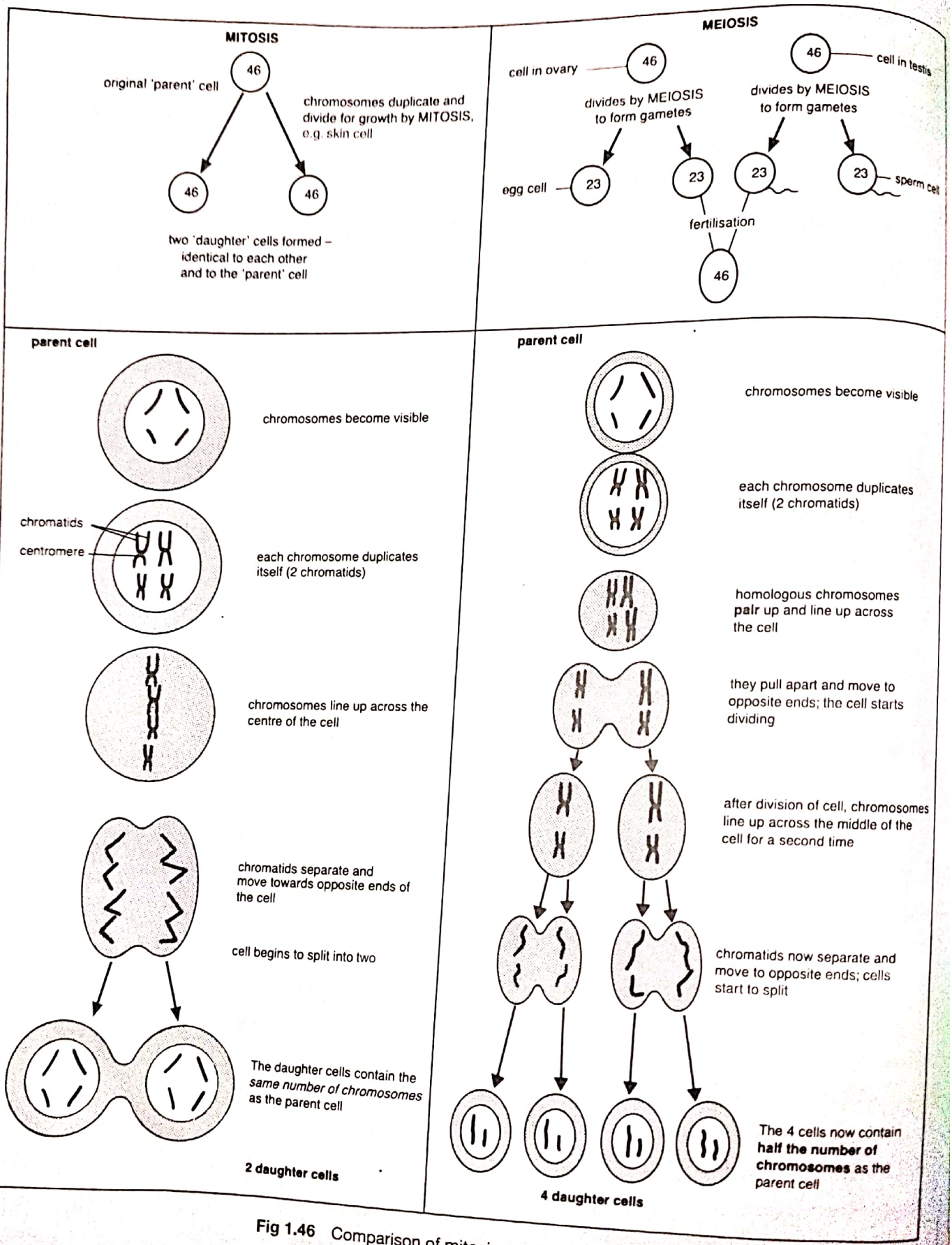


Fig 1.46 Comparison of mitosis and meiosis.

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9 a) Make a large drawing of a typical plant cell to show its ultrastructure. Label the following parts correctly and state their functions:
(i) nucleus
(ii) mitochondrion
(iii) endoplasmic reticulum
(iv) Golgi body
(v) lysosome
(vi) chloroplast
(vii) ribosome
(viii) vacuole
(ix) cell wall
(x) cytoplasm.

b) State (i) three similarities and (ii) three differences between plant and animal cells.

10 a) Name two types of tissues in (i) plants and (ii) animals.

b) Draw one cell of each type of tissue you have named in (a).

c) State one function of each type of tissue you have named in (a).

11 a) Define the following terms and, for each, give one example from plants and one example from animals:
(i) tissue
(ii) organ
(iii) organ system.

leaf, roots (of plants), blood, bone, palisade mesophyll cells, kidney, heart, epidermal cells, shoot (of plants).

b) Which of the structures listed above are:
(i) tissues
(ii) organs
(iii) organ systems.

c) State the function(s) of each of the structures listed.

12 a) What is cell division?

b) (i) Give five features that distinguish between the two types of cell division that occur in the mammalian body.
(ii) What is the significance of each type of cell division?

13 a) Define the terms mitosis and meiosis and state where they occur.

b) State four differences between mitosis and meiosis in a tabular form.

c) State the importance of mitosis and meiosis.

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6 Rocks

Learning objectives

After studying this unit, you should be able to:

1 describe the major types of rocks, their formation and characteristics
2 describe the process of weathering of rocks.

Background information

A rock is simply a large mass of stone or a mass of mineral matter of which the essential part of the Earth's crust is made up. These include loose incoherent inorganic masses, such as gravel and sand, and solid masses, such as limestone and granite.

The agricultural importance of rocks lies in the fact that it is the weathering of rocks that gives rise to the parent material from which soil is formed. Hence, parent material is one of the factors of soil formation. The other factors are climate, relief (or topography), living organisms and vegetation, and time.

Rocks and their characteristics

Rocks constitute an essential part of the Earth's solid crust because of their valuable mineral composition. Some of these minerals, including gold, diamond, aluminium, iron and the micas, are important sources of national wealth. The term 'rock' is, however, also applicable to slabs of stones or cliffs.

Rocks are commonly classified as igneous, sedimentary and metamorphic, based mainly on their mode of formation (Figure 1.47).

Igneous rocks

Igneous (from the Latin word *ignis* meaning 'fire') rocks are the oldest type of rock in the world. They are formed from a hot liquid mass called molten lava or **magma** in the centre of the Earth. They are called igneous rocks because the molten lava which forms them is produced by fire. Intense heat and pressure push the molten lava from the centre of the Earth to positions on or near the surface. Through cooling and solidification, the lava

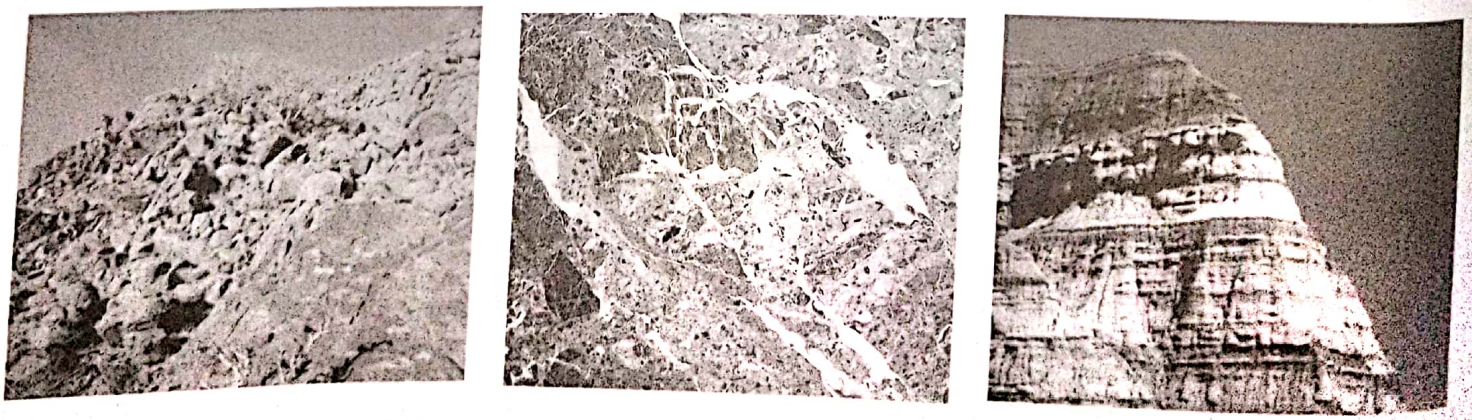


Fig 1.47 Rock types **(a)** igneous e.g. granite **(b)** metamorphic e.g. marble **(c)** sedimentary e.g. sandstone.

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is transformed into igneous rock. Most igneous rocks were formed millions of years ago, but they are still being formed today through volcanic activities.

Igneous rock formed from volcanic activity is fast cooling and therefore has fine crystals, e.g. **basalt**. Slower cooling igneous rock has larger crystals, e.g. **granite**. Generally, igneous rocks are massive, shiny and hard and are composed mainly of primary minerals, such as quartz, feldspars and hornblende.

Sedimentary rocks

Sedimentary (from the Latin word *sedere* meaning to 'sit') rocks are formed from the deposition and cementation of sediments in layers. Sediments are weathered products of other rocks and organic materials. Sedimentary rocks are therefore characterised by the presence of **strata** (layers) and **fossils** (hardened remains or traces of prehistoric plants or animals).

Sedimentary rocks are generally composed of secondary minerals, such as dolomite, gypsum, calcite and clay minerals. Examples of sedimentary rocks are:

- **sandstone** from sediments of granite
- **limestone** from sediments of calcite
- **shale** from compacted mud and silt
- **conglomerates** composed of cemented pebbles.

Because of the lines of weakness between the strata, sedimentary rocks are generally not as resistant to weathering as igneous rocks. They are sometimes referred to as stratified rocks.

Metamorphic rocks

These rocks result from changes in the form of either an igneous rock or a sedimentary rock – a process known as **rock metamorphosis**. Tremendous heat and pressure are the main known causes. Table 1.30 gives some examples.

Table 1.30 Formation of metamorphic rocks

Original rock	Type	Metamorphic rock formed
granite	igneous	gneiss
limestone	sedimentary	marble
shale	sedimentary	slate
sandstone	sedimentary	quartzite
gabbro	igneous	serpentine

The process of rock metamorphosis also alters the chemical composition of some of the constituent minerals of the original rock. As a result, metamorphic rocks formed from igneous rocks (composed mainly of primary minerals) will contain both primary and secondary minerals, e.g. gneiss and serpentine. Those formed from sedimentary rocks will contain chemically altered secondary minerals, e.g. slate and quartzite. Metamorphic rocks are generally dull and rough in appearance.

ACTIVITY 1 Identifying rocks

1. Visit a geological survey department if possible, and examine samples of different rock types.
2. Design a checklist to classify the different rocks.
3. Use this checklist to identify the rocks as igneous, sedimentary or metamorphic.
4. Discuss your findings with the class.

Weathering of rocks

Weathering of rocks is any process that disintegrates, decomposes or crumbles rock into smaller rock particles. On the basis of how this occurs, weathering is described as physical, chemical and biological.

Physical weathering (mechanical)

This type of weathering results in a decrease in the size of the rocks and the minerals they contain but not in a change in the chemical composition of the minerals. Physical weathering is common in the tropics where temperature, water and wind are its main causes.

Temperature

Sudden and wide temperature fluctuations, e.g. hot day and cold night temperatures, greatly influence the disintegration of rocks. This is as a result of the expansion of the rock minerals when the temperature is high and their contraction when the temperature falls. This continuous expansion and contraction sets up stresses in the rocks, causing them to crack and break down into smaller particles.

In cooler regions, where temperatures fall below freezing point, water in the crevices of rocks solidifies and expands in the process, causing the rock to crack under stress.

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Water

Moving water in streams and rivers, loaded with hard rock particles or sediments, has tremendous eroding power. The moving rock particles hit against one another and against rocks over which the water is moving. The impact causes the breakdown of the rocks. In extremely cold environments, glaciers literally grind away rocks over which they move.

Wind

Wind is moving air. Wind, especially in desert areas, carries sand particles which have an abrasive action on the surfaces of exposed rocks, causing small bits to chip off.

Less common causes of physical weathering of rocks are geological actions, such as Earth tremors and earthquakes.

Biological weathering

This type of weathering is described as biological because the weathering is caused by living organisms, including humans.

Biological weathering involves the cracking and breaking down of rocks under pressure, including stress from the growing roots of plants and the actions of humans in activities such as farming, road construction and building.

Green plants, algae, fungi and mosses cause biological weathering. Besides growing on rock surfaces and into rock crevices, creating considerable pressure (Figure 1.48), they also produce organic acids which dissolve rock minerals and assist in their disintegration.

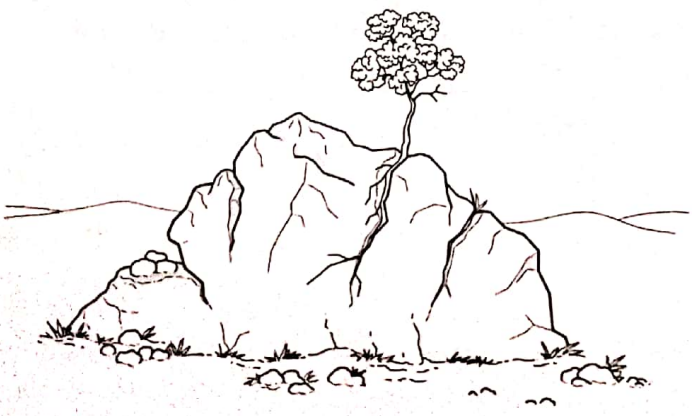


Fig 1.48 The roots of a plant growing in a rock crevice.

Chemical weathering

This involves the chemical decomposition of the mineral constituents of rocks. It is common in various humid regions and usually involves water.

Oxidation

This refers to the reactions between atmospheric oxygen and oxygen dissolved in rainwater with some rock minerals. For example, the oxidation of iron(II) oxide to iron(III) oxide in rocks carrying iron. The result is a less stable crystal structure. The rock therefore breaks down mechanically along its surfaces where the oxidation takes place.

Reduction

This involves the removal of oxygen from some rock minerals under poor drainage conditions characterised by oxygen deficiency. This also disturbs the stable crystal structure of the rock and causes its physical disintegration.

Carbonation

Carbonation is a reaction between inorganic carbonic acid in soil water and certain minerals in rocks, e.g. calcite in limestone. The insoluble calcite becomes soluble calcium bicarbonate, causing the limestone to fall apart.

Hydration

In hydration water molecules become rigidly attached to rock minerals, changing them into new minerals containing water of crystallisation. The rock expands, becomes soft and porous and physically breaks down as a result.

Hydrolysis

Unlike hydration, where water molecules merely attach themselves to the minerals, in hydrolysis there is a chemical reaction between water and the mineral to produce excess OH^- or H^+ ions. New products which carry no water of crystallisation may be formed, but the rock breaks down all the same.

Solution

In this reaction water on rock surfaces and in crevices performs its unique function of a universal solvent by dissolving soluble rock minerals. This accounts for the physical breakdown of rocks containing them.

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Self check

For questions 1 to 9, choose the letter that refers to the correct option.

1 Which chemical process of rock weathering produces a new mineral with water of crystallisation?
- **A** hydrolysis
- **B** hydration
- **C** solution
- **D** carbonation

2 An example of course-grained igneous rock is:
- **A** granite
- **B** basalt
- **C** gabbro
- **D** gneiss

3 Which of the following rocks contain fossils?
- **A** marble
- **B** slate
- **C** shale
- **D** granite

4 The following are all processes of chemical weathering of rocks except:
- **A** nitrification
- **B** carbonation
- **C** oxidation
- **D** reduction

5 Which of the following factors of soil formation is an end product of rock weathering?
- **A** climate
- **B** topography
- **C** parent material
- **D** time

6 The metamorphic rock serpentine is formed from:
- **A** limestone
- **B** sandstone
- **C** granite
- **D** gabbro

7 Which of the following rocks is/are easily weathered?
- **A** sedimentary rock
- **B** metamorphic rocks
- **C** igneous and metamorphic rocks
- **D** sedimentary and igneous rocks

8 During the formation of rocks the thickness of sediment deposits are reduced through:
- **A** metamorphosis
- **B** stratification
- **C** cementation
- **D** compression

9 Which of the following rocks is composed of cemented pebbles?
- **A** limestone
- **B** shale
- **C** sandstone
- **D** conglomerate

10 **a)** State two characteristics of each of the following rock types:
(i) igneous rocks
(ii) sedimentary rocks
(iii) metamorphic rocks.
b) Give a brief description of the formation of igneous rocks.

11 **a)** Distinguish between the following:
(i) physical and chemical weathering of rocks
(ii) oxidation and reduction
(iii) hydration and hydrolysis.
b) Explain how temperature causes physical weathering of rocks.

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1 Air movement

Learning objectives

After studying this unit, you should be able to:

1 explain the formation of land and sea breezes
2 identify the various types of air masses and describe their pattern of movement
3 describe the effect of moving air masses.

Background information

The planet Earth is surrounded by layers of gases: the troposphere (the nearest), the stratosphere, the mesosphere and the thermosphere. Together these make up the atmosphere. The sun's rays create changes in the properties of the air in the atmosphere. This results in a body of air with uniform properties which behave in a particular way. An **air mass** is a horizontal body of air over a large area, with uniform temperature, humidity (moisture) and pressure. Continuous changes in air mass pressure ensure continuous change that brings favourable and unfavourable changes to the Earth's immediate environment.

In the nearest layer to the Earth's surface, the troposphere, day and night temperature changes initiate interaction between the land and the sea air mass to form land and sea breezes. Changes in air mass also produce different weather conditions, such as storms. Through human activities, air mass that moves into higher parts of the Earth's atmosphere carry along pollutants, such as chlorofluorcarbons (CFCs) that tend to cause depletion of the protective ozone layer in the stratosphere. Other pollutants and CFCs in the atmosphere absorb more heat into the atmosphere causing global warming. Since air mass movements cross national frontiers, pollutants also cross frontiers. All these have direct effects on the survival of living and non-living things on Earth.

Land and sea breezes

Even though the sun is about 150 million km away from the Earth, nevertheless it keeps the Earth warm. This means that the sun gives out a large amount of radiant energy.

The Earth revolves around the sun in its orbit, creating different seasons. Each season has its own particular temperature and other weather conditions, such as relative humidity, air pressure and wind speed. In addition to the seasons the Earth also rotates round its axis, creating day and night. You have probably observed that temperatures during the day are different from those at night.

The Earth is roughly spherical in shape. This causes uneven warming. Also, about 77 per cent of the Earth's crust is covered by water. Water warms slowly whereas the land absorbs radiant energy more readily. This causes differences in the temperature over the sea and the land. In addition, the landscape of the Earth varies from plains and valleys to mountains of varied heights.

If you have ever visited or stayed in mountainous areas, such as Aburi, Abetifi, Amedzofe, Gambaga or Mampong in Ashanti, you will have observed that the daily temperatures are low. The Accra plains and Tamale plains as well as most of the Akan dissected peneplains (a plain created by erosion and without any notable feature) have warmer temperatures.

The uneven heating of the Earth's surface is due to:

- the curvature of the Earth's surface
- the rotation of the Earth, resulting in global winds

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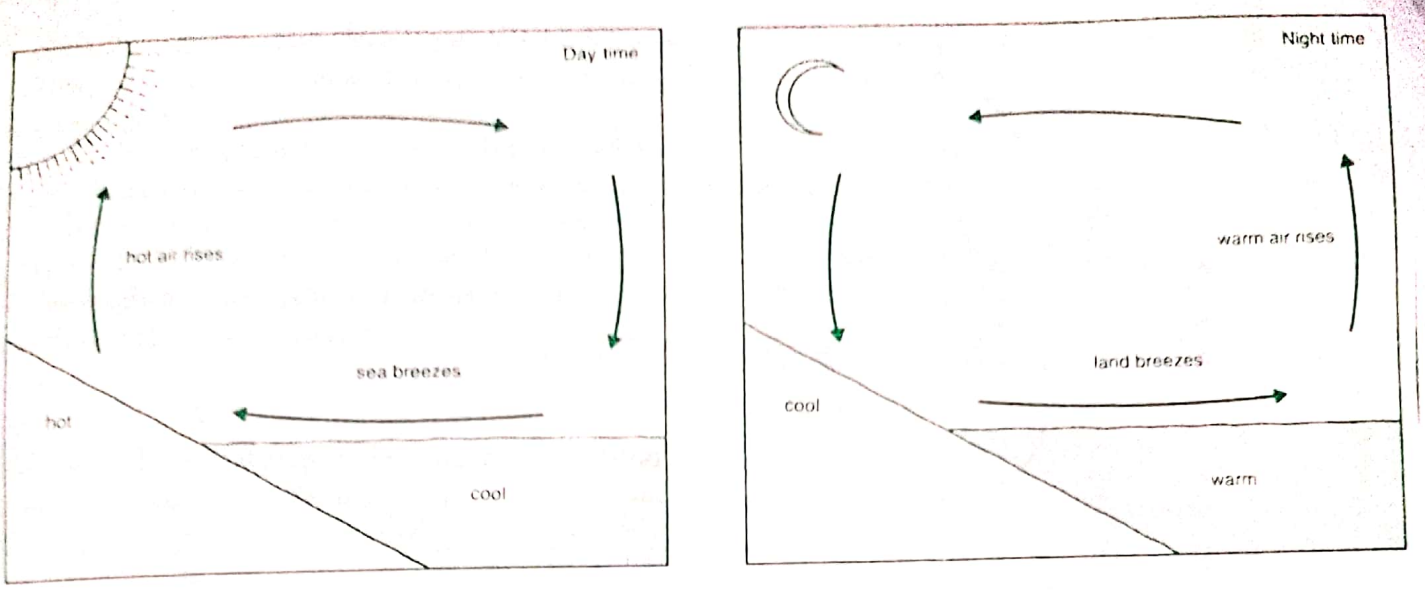


Fig 1.49 Land and sea breezes caused by convection currents.

- the revolution of the Earth around the sun, creating seasons
- the differences between land and sea temperatures.

Land and sea breezes are the result of convection currents (Figure 1.49). In the daytime **sea breezes** form when warmer, less dense air over the land rises, and cooler air above the sea blows in towards the land. At night the land cools down more quickly than the sea, so the warm air above the sea rises, and cool air from the land blows towards the sea as **land breeze**. The two processes take place continuously. These convection currents (winds) often bring clouds with them and produce rain along the coast.

Types of air mass – their movement and effects

An **air mass** is a large horizontal body of air with uniform temperature, humidity (moisture) and pressure within the area it covers. Its properties can change when it enters a new air mass or environment. A **wind** is an air mass which is moving horizontally on the Earth's surface. Winds move from an area of high pressure to that of lower pressure. Pressure is determined by the density of the air. In turn, density is also determined by temperature and moisture levels of a sample of air and hence direction of wind. Water vapour molecules are lighter than air molecules. At a higher moisture level the mass of air decreases and this decreases the density of the air (m/V). At a higher temperature the volume of a sample of air increases and this decreases the density (m/V) of the air mass. Similarly, at a lower temperature and in drier air the mass of air is bigger and its volume decreases, thus increasing air density.

> Generally, warm and moist air decrease air density and create low pressure. On the other hand, cold and dry air increase air density and create high pressure.

The air masses of the Earth circulate because of the uneven heating of the Earth. Air masses at the equator are heated, made lighter, rise and move towards the poles. A permanent doldrum (low pressure) is created around the equatorial region. At latitude 30° north and south the air that sinks causes a zone of high pressure referred to as the **horse latitudes**. As the air moves further away from the equator it cools and sinks, creating high pressure at the poles. These cool air masses at the poles flow back towards the low pressure belts near the equator. It is in the horse latitude that the Sahara desert exists. Most of the world's deserts are found in regions of light winds and calms.

Figure 1.50 is a diagram of the Earth's wind system. Air currents flow outwards across the Earth's surface from the horse latitudes. The rotation of the Earth also deflects winds to the right of their natural direction in the northern hemisphere and to the left in the southern

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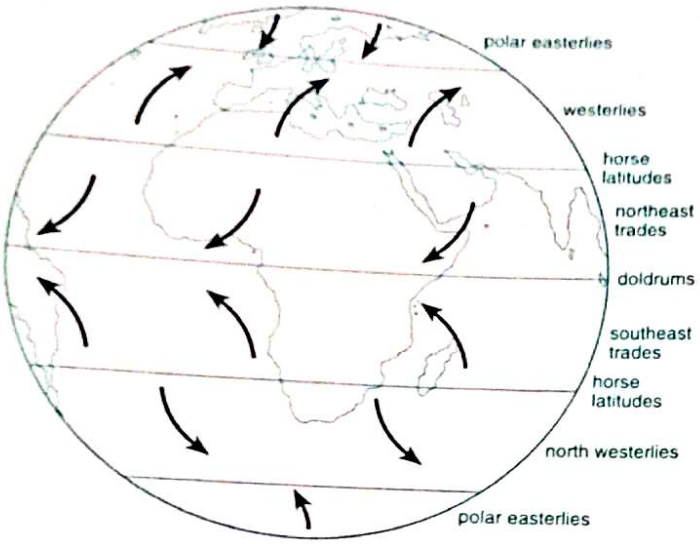


Fig 1.50 The Earth's wind system.

hemisphere. The winds that blow towards the equator are called the **trade winds**, and those that blow towards the poles are the **westerly winds** or **westerlies**. The westerlies converge with cold air currents called the **easterlies**. The easterlies are sinking cold and dense air moving from the poles to the equator.

When two air masses meet they do not mix, a front is formed. A **front** is the boundary formed between different air masses. A **storm** is a strong wind often accompanied by rain, snow and sometimes lightning and thunder. Storms are generally caused by a low pressure air mass area surrounded by a wind system. Hot rising air that creates the low pressure can form clouds that bring about the rain and thunderstorms. There are different forms of storms. They include cyclones, hurricanes, tornadoes and typhoons. Each is formed depending on the geographical location of the moving air mass, air moisture and temperature.

- **Hurricanes** – a violent destructive tropical storm with heavy rain and strong winds. It starts from low pressure areas near the equator of the Atlantic and Caribbean regions and becomes stronger in the north, northeast and northwest directions, e.g. Hurricane Katrina in the USA in 2005.
- **Tornado** – fast moving, violently swirling and funnel-shaped column of air mass that moves in a narrow path over land. It is highly destructive.
- **Typhoon** – a violent storm in the tropics of the Pacific and Indian oceans.
- **Cyclone** – a storm that whirls round while moving around low pressure centres. This is as a result of the intermingling of polar and subtropical air. The rotation of the Earth also deflects winds to the right of their natural direction in the northern hemisphere and to the left in the southern hemisphere. Between latitudes 30° and 65° north and south of the equator are transitional zones of changeable weather. In these zones unstable weather conditions create huge fronts and cyclones.

The warm air that rises at the equator by low pressure continues through high and low pressure, cool and warm air areas and eventually sinks to the ground. Near the ground, a high pressure system pushes the air back to the original low pressure area again near the equator to repeat the cycle. The cycle of warm rising and cold sinking air mass creates a convergence of trade winds on opposite sides of the equator called the inter-tropical convergence zone (ITCZ). The ITCZ is a moving air mass or wind front that bears heavy, sudden rain forming clouds. The ITCZ is a major influence on the weather in tropical areas, and it is a source of storms often mentioned in weather reports on radio, newspapers and TV.

The **weather** or **climate** of a place is the state of the atmosphere in terms of temperature, humidity, pressure, wind, clouds, rain and other minor conditions. Knowledge of weather helps humans in carrying out their daily activities with convenience. Meteorological or weather service departments in many countries forecast the weather. Their services include giving the location, speed, direction, temperature and pressure variations in winds and weather conditions. Early warning information on the severity of approaching storms and advice on safety measures to put in place to protect life and property are also given. The warning and advice are based on analysis of data communicated by a network of local and international weather stations. Various systems, such as ocean boats (buoys), weather balloons, aircraft and satellite stations in space, are used in collecting the data.

Precautions against the effects of severe storms

Fast moving air masses can cause storms. Storms may move with high speed horizontally and vertically or

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both. This can result in destruction of human life and physical structures, such as houses and public buildings in their path. Storms also cause rain, lightning and thunder. Severe thunderstorms can result in flooding, erosion and also destruction of life and property. Precautions need to be taken to protect life and property. The major decision that must be made when a storm approaches is whether to stay or go. Generally, do not panic, be ready to evacuate, watch how the storm develops and be ready to protect yourself, listen to any radio and TV warnings, and in some cases stockpile food and keep reserve water.

ACTIVITY 1 Preparing for floods

1 *Work in groups* of five.

2 Discuss first, then design a plan for how to reduce constant flooding in an area that you live in.

3 Write a short report for discussion in class. The report should include the following:
   a) Education of the people in the community about their practices which may cause the flooding.
   b) How to carry out the plan when the rains come.
   c) How to handle the flood if it occurs again.

Air masses and pollutants

The wind (moving air mass) carries pollutants from layer to layer, causing changes in the natural state of each layer. For example, the atmosphere contains a layer of ozone at high altitude in the stratosphere that filters out harmful ultraviolet radiation from space, protecting life on the Earth. However, **chlorofluorocarbons** (CFCs) are destroying the ozone layer, allowing the ultraviolet rays to reach living organisms, often afflicting them with deadly diseases, such as skin cancer.

The world may be regarded as a global village. What happens in one area of the world can easily be conveyed to other areas by various means, such as water and air movements. Air masses play a dominant role in transporting pollutants from one region to another on the Earth's surface, for example, from industrialised to less industrialised countries. CFCs have also been identified as greenhouse gases which are causing global warming.

Harmful gases, such as sulphur dioxide and nitrogen oxides, are blown by air masses from one region to the other. These gases pollute the air and harm the environment. For example, they produce acid rain which destroys biodiversity.

Other human activities release harmful radioactive dust and gas pollutants into the air. These harmful materials are also carried by winds from place to place across national borders as fallouts.

PROJECT 1 Searching for information on storms

1 Use one or more of the following sources for information on storms:
   a) internet
   b) Microsoft Encarta
   c) newspaper
   d) news stations
   e) meteorological office/station
   f) personal accounts.

   The information should include the following:
   a) types of storms
   b) location of storms
   c) early warning systems and forecasting methods.

2 In groups of three, write a report and submit it to your teacher for discussion in class.

Self check

For questions 1 to 7, choose the letter that refers to the correct option.

1 Nature has provided for the purification of the atmosphere. Which of the following are concerned with the purification of the atmosphere?
   I filtration of harmful ultraviolet radiation
   II reflection of radiant energy
   III rotation of the Earth

   A I, II and III
   B I only
   C I and II
   D II and III

2 The uneven heating of the Earth's surface is caused by all of the following except:
   A the curvature of the Earth
   B the rotation of the Earth
   C differences in the absorption of radiant heat energy by water and land
   D differences in the velocities of seismic waves

3 Land and sea breezes are the result of:
   A convection currents
   B the different phases of the moon
   C the revolution of the Earth
   D volcanoes

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4 The deserts of the world are closely linked with:
- A the prevalence of cyclones
- B regions of light winds and calms
- C regions of doldrums
- D regions with fronts

5 Storms are formed when:
- A different air masses rise and separate
- B temperature falls and rises
- C air masses at low pressure meet a wind
- D pollutant amount in the atmosphere changes

6 Moving air masses can cause the following:
- I storms
- II pollution
- III land and sea breeze

- A I only
- B I and II
- C II and III
- D I, II and III

7 In a public meteorological service the following can be provided:
- A night and day temperatures and early warning of a storm
- B night and day temperatures only
- C domestic quality of drink water and precautions to take during a typhoon
- D satellite images of air mass movement only

8 a) Which factors contribute to the uneven heating of Earth?
b) List any three natural occurrences arising from uneven heating of the Earth.

9 a) What are trade winds?
b) Describe briefly how trade winds are formed.
c) Describe briefly how different air masses can inter to form rain.

10 Land and sea breezes are the result of convectic currents during the day and night.
a) State what time of the day, normally, that a:
(i) sea breeze is formed
(ii) land breeze is formed.
b) Describe briefly how a:
(i) sea breeze is formed
(ii) land breeze is formed.

11 a) What is an air mass?
b) When does an air mass create a:
(i) wind?
(ii) front?
(iii) cyclone?
b) Discuss the role an air mass has in:
(i) depletion of the ozone layer in the Ear atmosphere
(ii) determining the weather.

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2 Nitrogen cycle

Learning objectives

After studying this unit, you should be able to:

1 describe the nitrogen cycle
2 explain the importance of the nitrogen cycle to plants and animals.

Background information

Nitrogen is a macro-nutrient which has the quickest and the most significant effect on plant growth and development. Primarily, nitrogen encourages vegetative growth and gives plant leaves their characteristic deep green colour. In addition, it regulates the utilisation by plants of phosphorus, potassium and some other plant nutrients. In cereal crops nitrogen increases protein percentage and plumpness of grains. It is, therefore, the most limiting factor in plant growth. There is a compelling need for both artificial and natural ways of maintaining adequate amounts of absorbable nitrogen; that is, nitrate and amonuim ions in soil to ensure sustainable production of crop plants for use by both humans and livestock.

The nitrogen cycle

The role of nitrogen in plant nutrition and in crop yield is so crucial that it is the most limiting essential nutrient in plant growth. Soil nitrogen is continuously being lost from the soil through both artificial and natural means, such as crop removal, soil erosion, leaching and denitrification. Plants cannot make direct use of atmospheric nitrogen. It first needs to be transformed into an absorbable form, such as ammonium (NH_4^+) and nitrate (NO_3^-) ions.

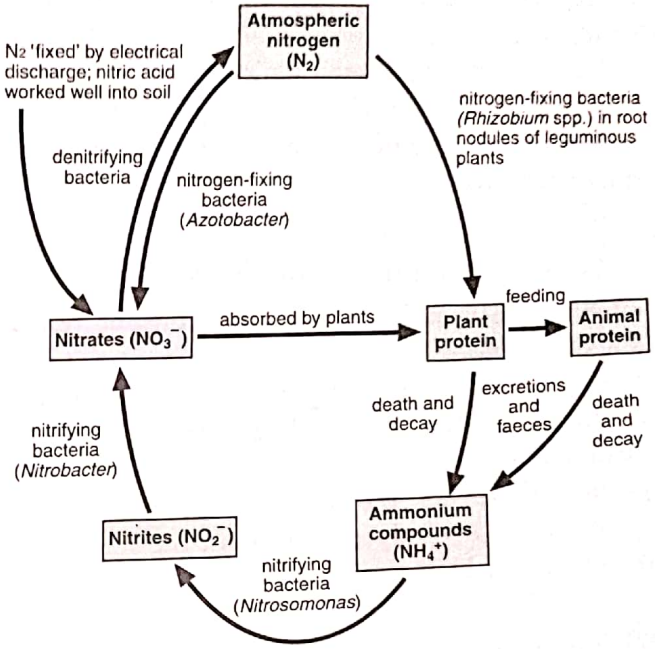


Fig 1.51 The nitrogen cycle.

The **nitrogen cycle** describes the continuous interlocking succession of events and processes through which nitrogen lost from the soil is naturally replenished (Figure 1.51).

The various processes that constitute the cycle are now described.

Nitrogen fixation

This refers to the ways by which atmospheric nitrogen gets into the soil. Nitrogen is fixed in the soil either chemically or biologically. Chemical nitrogen fixation is the result of lightning in the atmosphere. The resulting electrical discharge releases sufficient energy to activate atmospheric nitrogen and oxygen to chemically combine to form oxides of nitrogen. These oxides react

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with rainwater which washes them as nitrous acid and then nitric acid into the soil, where the nitric acid is oxidised into NO_3^- ions by losing its hydrogen ions. The nitrate is then absorbed by plant roots.

Biological nitrogen fixation, on the other hand, involves the activities of nitrogen-fixing bacteria. These species of bacteria take in atmospheric nitrogen via soil air. The nitrogen is released for plant use when they die and their organic residues are mineralised.

One group of these bacteria, *Rhizobium* spp., take in the nitrogen while living in a symbiotic association in the root nodules of leguminous crops. The other group takes in the nitrogen while living freely in the soil. *Azotobacter* spp. (active under aerobic and neutral soil conditions) and *Clostridium* spp. (active under anaerobic soil conditions) are examples of this second group of bacteria.

Production of ammonium ions

When animals and plants die their organic residues are decomposed by putrefaction bacteria. The first nitrogenous end product of the decomposition is amino acids. These then undergo a further process to yield ammonium salts. Some plants absorb NH_4^+, particularly grasses. The bulk of it, however, undergoes nitrification to produce NO_3^- ions, the form of soil nitrogen absorbed by most plants.

Nitrification

This is a two-stage oxidation process. The first stage is the conversion by *Nitrosomonas* bacteria of NH_4^+ ions to nitrite (NO_2^-) ions. This is immediately followed by the second stage during which *Nitrobacter* bacteria oxidise the nitrite (NO_2^-) into nitrate (NO_3^-) ions.

Denitrification

This process involves the reduction of the nitrate ions into gaseous nitrogen which escapes from the soil. The nitrate is reduced by denitrification bacteria such as *Planococcus* spp. which, under anaerobic conditions, remove and use oxygen from the nitrate for respiration. The loss of soil nitrogen through denitrification is much less than the loss through leaching, soil erosion and crop removal.

Importance of the nitrogen cycle

The nitrogen cycle is important because it:

- supplies available forms of nitrogen (nitrate ions) from the non-available atmospheric nitrogen for plant use
- releases nitrogen locked up in plant and animal tissues
- sustains beneficial microbial growth and activities in the soil, thereby improving soil structure and its productivity
- improves soil fertility and nutrient balance
- avoids the accumulation of foul smelling plant and animal tissues on and in the soil
- supplies nitrogen to plants for liberal vegetative growth which serve as feed for both humans and their livestock.

ACTIVITY 1 The role of bacteria in the nitrogen cycle

1 Look at the diagram of the nitrogen cycle (Figure 1.51)

2 *Work in groups* to discuss what would happen to plant and animal life if there were no bacteria in this cycle.

Self check

For questions 1 to 9, choose the letter that refers to the correct option.

1 Which group of bacteria oxidise NH_4^+ ions into nitrite (NO_2^-) ions?
A *Rhizobium* B *Azotobacter*
C *Nitrosomonas* D *Nitrobacter*

2 Plants absorb soil nitrogen in the form of:
A nitrogen gas B ammonia gas
C nitrite gas D nitrate ion

3 Which of the following bacteria fixes nitrogen in the soil?
A *Planococcus* B *Azotobacter*
C *Nitrosomonas* D *Nitrobacter*

4 The oxidation of nitrite into nitrate is termed:
A denitrification B nitrification
C mineralisation D ammonification

5 A common deficiency symptom of nitrogen in plant nutrition is:
A marginal browning of leaves
B death of older leaves
C yellowing of older leaves
D yellowing of fresh leaves

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6 In the nitrogen cycle which of the following bacteria is active under anaerobic conditions?

A *Rhizobium* **B** *Azotobacter*
C *Nitrosomonas* **D** *Clostridium*

7 Which of the following nitrogenous fertilisers supplies the greatest amount of nitrogen weight by weight?

A NPK **B** urea
C ammonium sulphate **D** ammonium nitrate

8 The most important way nitrogen is lost from the soil is through:

A soil erosion **B** leaching
C denitrification **D** volatilisation

9 The chemical symbol of nitrate is:

A NO_3^- **B** NO_2^-
C NO **D** N_2O

10 **a)** State three functions of nitrogen in plant nutrition.
b) Draw an annotated diagram of the nitrogen cycle.

11 **a)** Describe the chemical fixation of nitrogen during lightning.
b) Explain the following terms as used in the nitrogen cycle:
(i) symbiotic nitrogen fixation
(ii) non-symbiotic nitrogen fixation
(iii) nitrification
(iv) denitrification.

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1 The skeletal system

Learning objectives

After studying this unit, you should be able to:

1 describe the structure and functions of the mammalian skeleton.

Background information

Animal movement is extremely diverse involving swimming, hopping, walking, running, crawling and flying. Many animals, like an adult sponge in the sea, stay in one place and move only certain parts of their bodies. Most animals, however, exhibit more movement. Active travel from place to place is also called locomotion.

Locomotion in all its forms requires that an animal expends energy to overcome two forces that tend to keep it stationary: friction and gravity. Primarily, therefore, a skeleton is needed to overcome one or both of these forces. For animals to undertake any form of movement, be it in water, in air or on land, they must have rigid body parts to push against the ground or to apply force against air and water. An animal could not move without its skeleton.

The mammalian skeleton

A skeleton may be defined as the hard parts of an animal's body to which muscles are attached (Figure 1.52). It forms the framework of the body and consists of bones, cartilages and ligaments which bind them together.

There are two main types of skeleton:

- exoskeleton
- endoskeleton.

The **exoskeleton** covers the outside of the body. This is common in arthropods such as crabs, prawns, scorpions and some insects. It consists of two main substances, namely chitin and cuticle. The **endoskeleton** lies within the main body muscles. This is characteristic of vertebrates like humans, goats, cats, dogs and monkeys. The human skeleton contains approximately 206 individual bones.

The endoskeleton is divided into two main parts (Figure 1.53):

- **The axial skeleton** – made up of the skull, the vertebral column (backbone or spine) and the ribs and sternum (breast bone).
- **The appendicular skeleton** – consisting of the limbs (arms and legs) and the limb girdles (pectoral girdle or shoulder and pelvic girdle or hips).

The skull and the vertebral column together with the ribs form the **axial skeleton**; the limbs and the limb girdles together form the **appendicular skeleton.**

Functions of the mammalian skeleton

The functions of the mammalian skeleton are as follows:

- **Support** – it provides a rigid framework and supports the body.
- **Protection** – it protects delicate internal organs, e.g. the ribs protect the lungs and the heart while the skull protects the brain.
- **Definite shape** – it gives constant shape to the body.
- **Muscle attachment** – it provides a surface for the attachment of muscles.
- **Movement** – it provides a series of levers for movement.
- **Formation of blood cells** – the red blood cells and some of the white blood cells are formed in the bone marrow.

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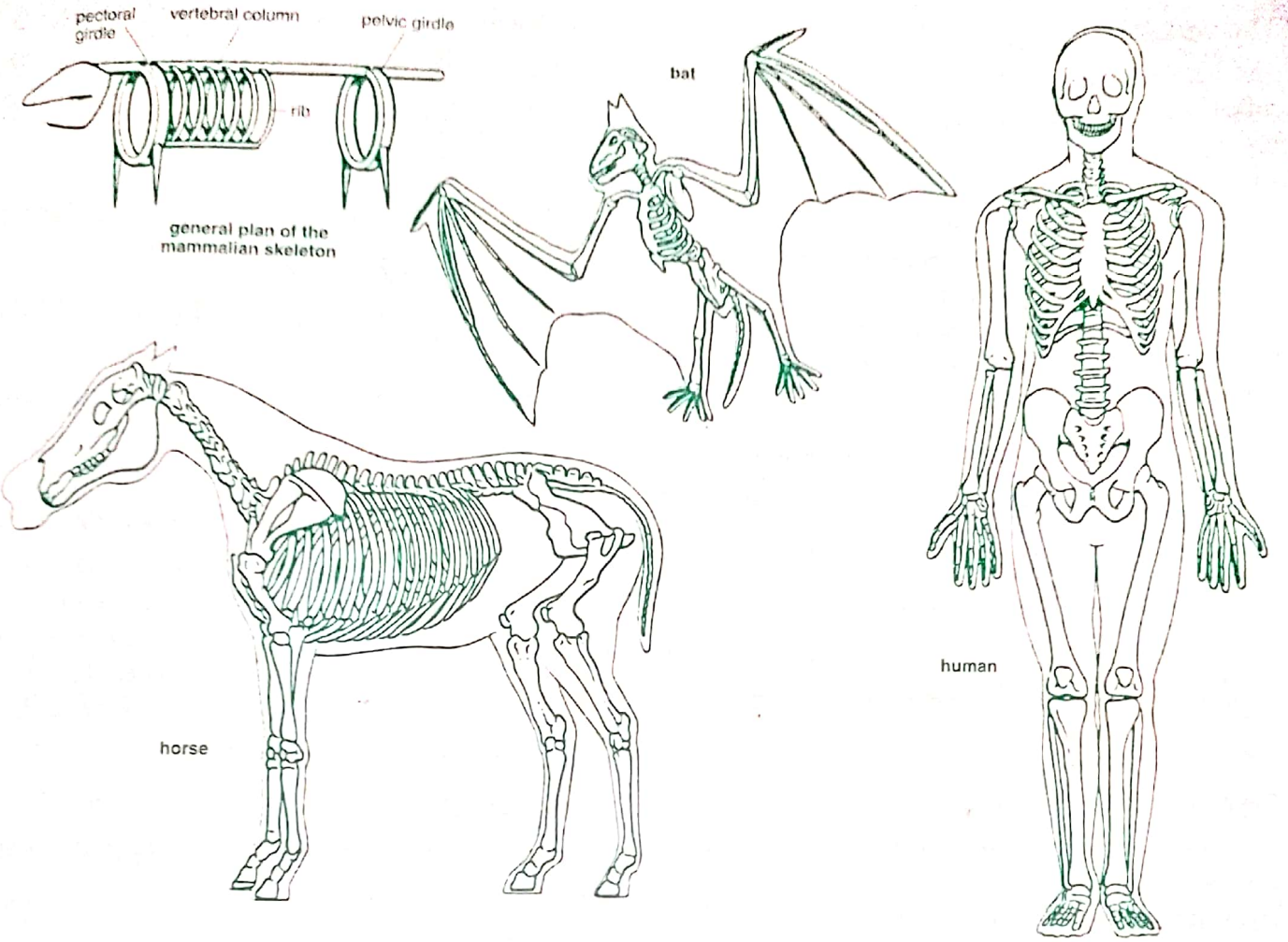


Fig 1.52 The mammalian skeleton.

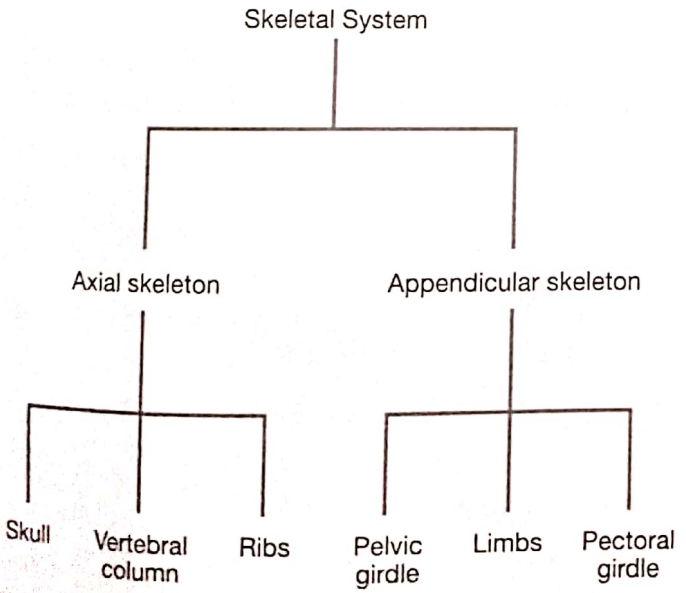


Fig 1.53 A scheme showing the main divisions in the mammalian skeletal system.

- **Respiration** – the ribs and their intercostal muscles contribute to the breathing action of the body.
- **Socket** – it provides sockets in which important organs are located, e.g eye socket and jaw bones.

The axial skeleton

The skull

The skull is made up of three regions, namely:

- cranium (brain case)
- face
- lower jaw.

The skull has immovable joints called sutures. The main function of the skull is housing and protection of the brain.

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The vertebral column

The vertebral column consists of a chain of small bones called vertebrae (singular: vertebra) which are stacked one upon the other. A cavity called the neural canal runs through the centre of each vertebra forming a continuous space in the chain.

The vertebral column supports the skull and the pectoral and pelvic girdles. It also protects the spinal cord that runs through it from the brain to the sacrum.

There are five different types of vertebrae which occur at various regions of the backbone (Table 1.31).

Table 1.31 Types of vertebra in the backbone

Type of vertebra	Location	No. in humans
cervical vertebra	neck	7
thoracic vertebra	thorax	12
lumbar vertebra	upper abdomen	5
sacral vertebra	lower abdomen	7
caudal vertebra	tail/coccyx	4

Cervical vertebra

In humans the first vertebra is called the atlas vertebra and the second is called the axis vertebra.
The main features of the cervical vertebra (Figure 1.54) are:

- short and less prominent neural spine
- short transverse processes
- presence of vertebraterial canals.

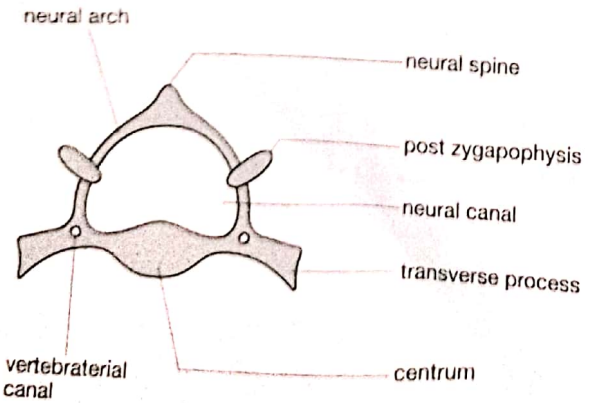


Fig 1.54 Anterior view of cervical vertebra.

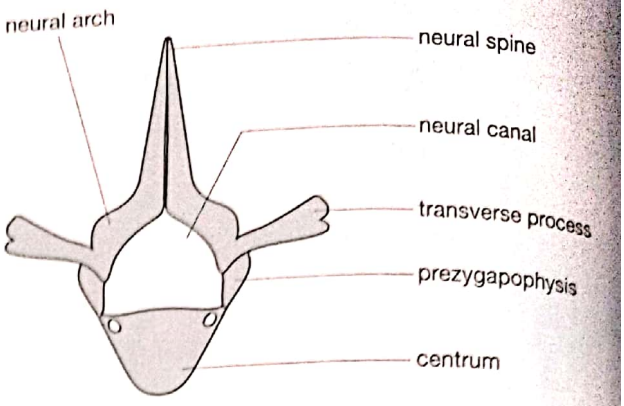


Fig. 1.55 Anterior view of thoracic vertebra.

Thoracic vertebra

The main features of the thoracic vertebra (Figure 1.55) are:

- long neural spine
- long transverse processes
- transverse process shorter than the neural spine
- articular facets for ribs present
- no vertebraterial canals present.

Lumbar vertebra

The main features of the lumbar vertebra (Figure 1.56) are:

- prominent neural spine
- well-developed transverse processes
- transverse processes longer than the neural spine
- no articular facets for ribs.

Sacral vertebra

The sacral region consists of five vertebrae immovably fixed to form a rigid bony structure called the sacrum.

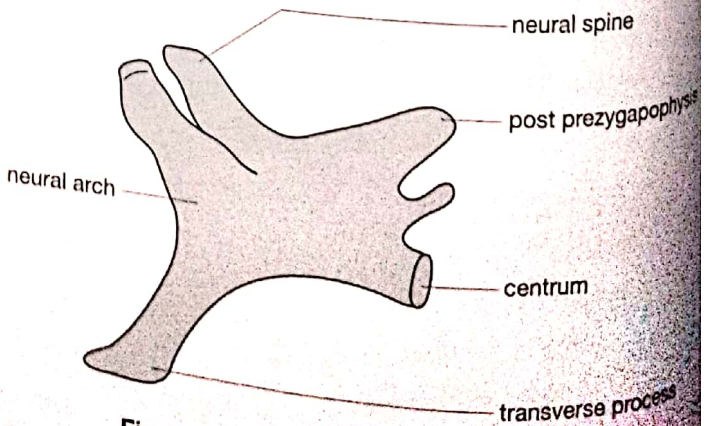


Fig 1.56 Side view of lumbar vertebra.

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Caudal (tail) vertebra

In humans four of these bones are fused together to form the coccyx. These vertebrae have no neural canal and no transverse processes.

The appendicular skeleton

The appendicular skeleton consists of the limbs and the limb girdles (Figure 1.57). The limbs are divided into fore-limbs and hind-limbs.

Fore-limbs

The fore-limbs are divided into five regions:

- **Humerus** – a long single bone in the upper arm.
- **Radius and ulna** – make up the fore-arm. The ulna is longer than the radius.
- **Carpals** – nine small bones making up the wrist.
- **Metacarpals** – make up the bones of the hand. They are five and articulate with the carpals and the digits.
- **Phalanges or digits** – the bones of the fingers. Each phalange ends in a claw or nail.

Hind-limbs

The hind-limbs are divided into five regions:

- **Femur** – a long single bone in the thigh.
- **Tibia and fibula** – make up the shank. The tibia is longer than the fibula.
- **Tarsals** – nine small bones making up the ankle.
- **Metatarsals** – make up the bones of the foot. They are five and articulate with the tarsals and the digits.

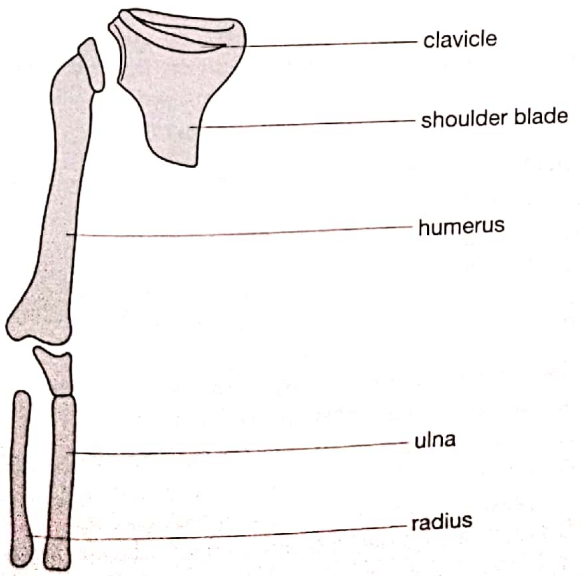


Fig 1.57 Pectorial/shoulder girdle and fore-limbs.

- **Phalanges** – the bones of the toes. Each of the phalanges ends in a claw or nail.

Human beings have pentadactyl limbs, which means that both fore-arm and the shank (tibia and fibula) end in five phalanges or digits (Figure 1.58).

ACTIVITY 1 Functions of parts of the mammalian skeleton

1 *Work in groups* to examine the major parts of the mammalian skeletons or by looking at figure 1.52

2 Discuss the functions of the major parts of the mammalian skeleton.

Joints

A joint may be defined as a spot where two or more bones meet. Joints allow movement.

Types of joint

- **Ball-and-socket (universal) joints** – found at the shoulder and hip. They allow movement in all planes, e.g. shoulder joint and hip joint.
- **Hinge joint** – found at the elbow and knee and allows movement in one plane only.
- **Gliding joints** – found between bones in the wrist and ankle where one bone moves over the surface of another.
- **Fixed joints** – do not allow movement, e.g. in the skull.

Movement of the elbow joint

Muscles work in pairs. One contracts while the other relaxes to produce movement. Such a pair of muscles across a joint is described as an antagonistic pair of muscles.

Biceps and triceps muscles are responsible for movement of the arm. For the arm to bend, the biceps contracts whilst the triceps relaxes. To straighten the arm, the biceps relaxes and the triceps contracts.

The biceps are also called flexors because they bend the arm. The triceps, on the other hand, straighten the arm and are called extensors.

Skeletal disorders

- **Osteoporosis** – this is related to hormonal changes that accompany ageing. Bones may become thinner, more porous and easily broken.

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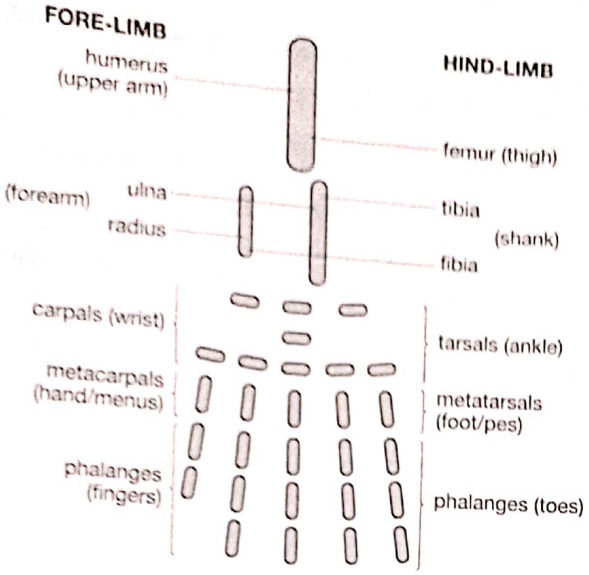


Fig 1.58 The pentadactyl limb plan involving the fore-limbs and hind-limbs.

- **Arthritis** – this is due to the inflammation of the joints, which causes swelling. This makes movement difficult and painful. The swelling and pain may be caused by wear and tear of cartilage tissues, osteoarthritis or hardening of cartilage and other tissues around the joints (rheumatoid arthritis).

Injuries to bones and joints

- **Fractures** – these are broken bones and are sometimes associated with wounds. They are always the result of accidents.
- **Sprains** – they occur as a result of less serious accidents. They are injuries to the tendon and ligaments around joints.
- **Dislocation** – this results from injuries to joints and the most common ones occur in the shoulder joints and the joints in the fingers and toes.

Friction in mammals

Friction must be exerted between the sole of the feet or paws of the animal and the ground so that the animal can move. The toes dig into the soil to increase the static friction: hence the shape of the hoofs of horses and cattle.

At the same time, friction within the mammal must be reduced, again so that it can move. The parts of the limbs and movable parts that need lubrication are in the joints. The limbs are ball-jointed with a covering of cartilage, which is lubricated. The knuckles, knee and ankle joints are lubricated with **synovial fluid** to reduce friction. The wrists have eight bones to reduce the friction between them.

Self check

For questions 1 to 8, choose the letter that refers to the correct option.

1 The skeleton consists of:
- **A** bones, cartilages and fluid
- **B** bones, ligaments and membrane
- **C** bones, cartilages and ligaments
- **D** bones and ligaments

2 Below is a list of parts of the mammalian skeleton:

I skull **II** vertebrae **III** clavicle **IV** humerus
V tibia **VI** fibula **VII** femur **VIII** radius
IX ulna **X** pelvic girdle

The appendicular skeleton includes all the parts listed above except:
- **A** I and II
- **B** III, IV and V
- **C** VI, VII and VIII
- **D** IV, VI and VII

3 All of the following structures are found in a joint except the:
- **A** ligament
- **B** synovial fluid
- **C** metatarsal
- **D** cartilage

4 Thoracic vertebrae differ from the other vertebrae by the possession of:
- **A** long neural spine and facet on the centrum
- **B** short neural spine and facet on the transverse process
- **C** odontoid process and reduced centrum
- **D** stout centrum and vertebraterial canals

5 Which of the following mammalian vertebrae are nearest to the skull?
- **A** cervical
- **B** thoracic
- **C** lumbar
- **D** sacral

6 The sequential arrangement of vertebrae from top to bottom along the vertebral column is:
- **A** sacral, cervical, thoracic, lumbar, caudal
- **B** thoracic, lumbar, caudal, cervical, sacral
- **C** cervical, thoracic, lumbar, sacral, caudal
- **D** cervical, lumbar, thoracic, sacral, caudal

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7 The precise location of the atlas is:
- **A** between the skull and the axis
- **B** the front of the rib cage
- **C** between the lumbar vertebrae and the sacrum
- **D** within the pectoral girdle

8 The appendicular skeleton is made up of the:
- **A** skull and vertebral column
- **B** ribs and vertebral column
- **C** limbs and limb girdles
- **D** thoracic and lumbar vertebrae

9 **a)** (i) Name the types of vertebrae found in mammals.
(ii) State the region of the mammal's body where each type of the vertebra you have named in (a)(i) is found.

b) Describe the basic structure of the mammalian vertebrae, indicating the functions of the parts described.

10 **a)** What is a skeleton?

b) Name the main types of skeleton found in animals and, for each type, give one example of an animal in which it is found.

c) Name five functions of the mammalian skeleton?

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2 Reproduction and growth in plants

Learning objectives

After studying this unit, you should be able to:

1 identify parts of a flower and variations in flower structure
2 describe the processes of pollination and fertilisation
3 describe different types of fruits
4 describe the structure of seeds and state the functions of their parts
5 describe the mechanisms of seed and fruit dispersal
6 describe the process and conditions necessary for germination
7 describe vegetative (asexual) reproduction in plants.

Background information

Reproduction occurs in all living things. It is the process by which living things give rise to new individuals of their own kind. It prevents the **extinction** (complete dying out) of species, that is, it perpetuates species.

There are two types of reproduction: **sexual** and **asexual**.

- Sexual reproduction involves **fertilisation** – the process in which the nuclei of male and female **gametes** or sex cells fuse to form a **zygote**. The zygote grows and develops into a new individual of the same kind of organism.
- Asexual reproduction does not involve fertilisation. A common example of asexual reproduction found in some plants is vegetative reproduction. This involves the development of a new plant from a vegetative part of a plant, e.g. a piece of stem used as a cutting develops into a new plant. The new plant is genetically identical to the plant from which the vegetative structure was taken.

Structure of the flower

A flower is part of the shoot system of a plant, modified for sexual reproduction. It bears the sex organs that produce male and female gametes. A flower develops from a flower bud. Depending on the position of the bud a flower may be described as **terminal** when it is located at the tip or apex of the stem, **axillary** when it is found in the axil of a leaf or **cauline** when it is directly on the stem (Figure 1.59). It may be solitary (single) or in clusters (groups). A cluster of flowers is called an **inflorescence**.

An **inflorescence** is a group of flowers having a common stalk.

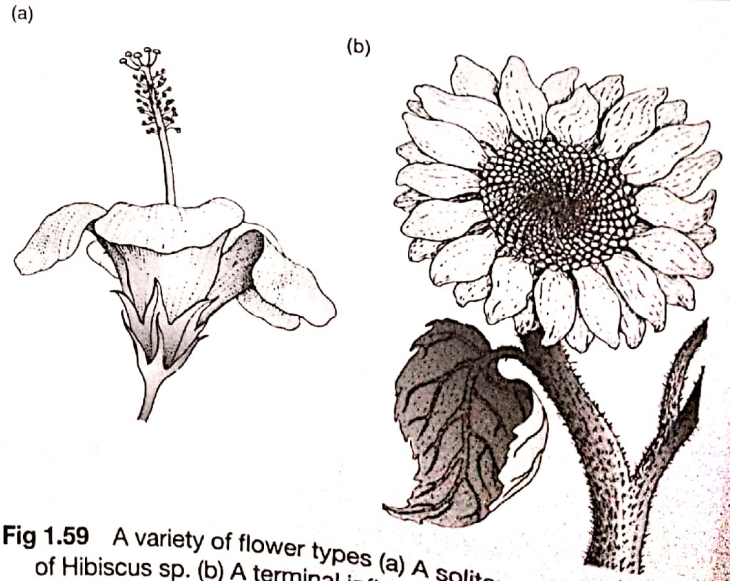


Fig 1.59 A variety of flower types (a) A solitary, axillary flower of Hibiscus sp. (b) A terminal inflorescence of sunflower.

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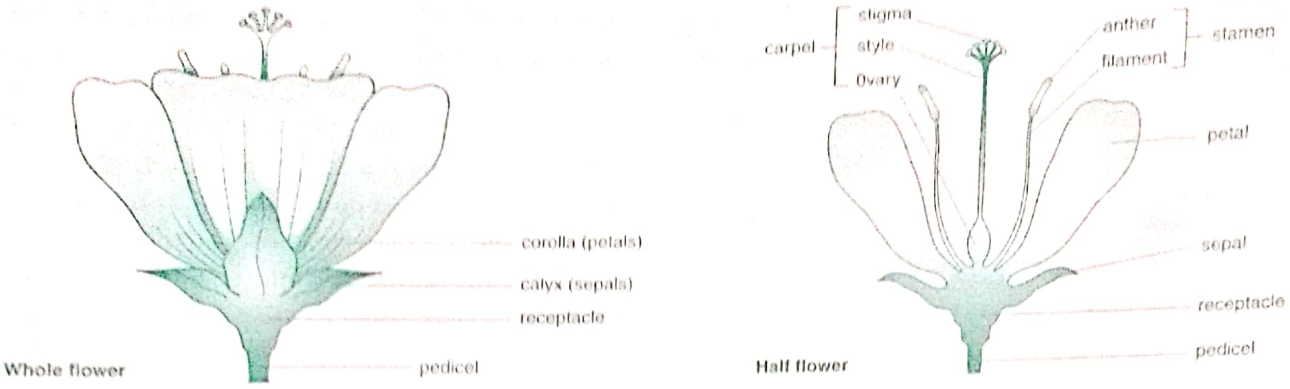


Fig 1.60 Generalised flower structure.

A generalised structure of a flower is shown in Figure 1.60. The stalk of an inflorescence is called the **peduncle**. Each flower has its own stalk called a **pedicel**. Some flowers lack a stalk and are described as **sessile** flowers.

A flower bears floral leaves arranged in concentric circles called **whorls**. The floral leaves are attached to a **receptacle,** which is the swollen tip of the pedicel. Generally, a flower has four whorls:

- calyx
- corolla
- androecium
- gynaecium.

Calyx

The calyx is the outermost whorl and consists of sepals. Sepals are small and green in colour in most flowers. They may be free from each other or fused. Some flowers, however, have large, brightly coloured sepals to attract animal pollinators. The calyx protects the flower at the bud stage and supports the inner whorls.

Corolla

This lies inside the calyx and consists of **petals**. These are usually large, brightly coloured and often scented to attract animal pollinators. They may be free or fused. Brightly coloured petals may also possess **nectaries** which produce nectar, a sugary liquid. The corolla protects and supports the whorls inside it.

In some flowers the calyx and corolla are similar in size and colour and cannot be distinguished from one another. Each is then called a **perianth segment** and together they form the **perianth**.

Androecium

This is the whorl immediately inside the corolla. It consists of **stamens** – the male sex organs. Each stamen consists of an **anther** and a **filament** (Figure 1.61). The anther is a four-lobed structure which produces **pollen grains**. The filament is a stalk that supports the anther. The stamens may be free or fused in various ways.

Gynaecium

The gynaecium is the innermost whorl. It consists of one or more **carpels**. The carpel is the female sex organ of the flower and produces the female gametes. Each carpel consists of three parts: ovary, style and stigma.

The **ovary** is the enlarged base of the carpel. It contains one or more **ovules**. A gynaecium consisting of only one carpel is described as **monocarpous**, e.g. *Caesalpinia pulcherrima* (pride of Barbados), *Crotalaria retusa* (rattle box), *Delonix regia* (flamboyant). The gynaecium may also consist of many free carpels and it is described as **apocarpous**, e.g. rose, *Bryophyllum*. If the gynaecium consists of many fused carpels it is described as **syncarpous**, e.g. *Hibiscus*, tomato, orange.

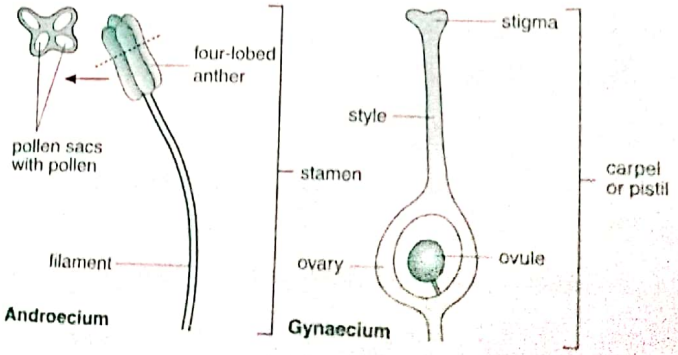


Fig 1.61 Structure of the androecium and gynaecium.

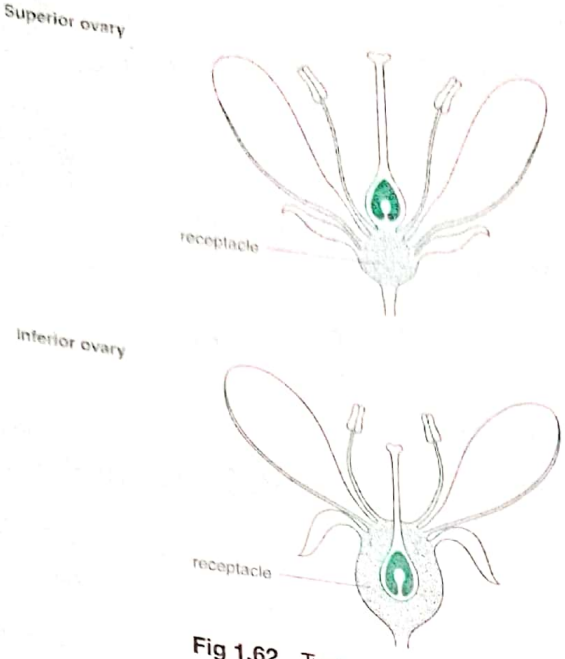


Fig 1.62 Types of ovary.

Each ovule is attached to the inner wall of the ovary at a point called the **placenta**. Each ovule produces one female gamete called the **ovum** (egg). The ovary is described as **superior** when it is situated above the other floral leaves on the receptacle, and **inferior** when it is below the other floral leaves (Figure 1.62. The inferior ovary is buried in the receptacle. The tissues of the receptacle may offer protection for the ovary against mechanical injury.

The **style** is the stalk that connects the stigma to the ovary. The **stigma** is a sticky, hairy or feathery apex of the style that receives pollen grains during pollination.

A flower is described as **radially symmetrical** (actinomorphic) when two mirror halves can be obtained by cutting a longitudinal section through many vertical planes. In such a flower the floral leaves in each whorl are similar in size and shape, e.g. *Ipomoea* sp. (Figure 1.63a). It is **bilaterally symmetrical** (zygomorphic) when two mirror halves can be obtained by cutting the flower longitudinally through only one particular vertical plane, e.g. *Crotalaria* sp. (Figure 1.63b).

When the androecium and gynaecium are both present in the same flower it is described as **bisexual** or a hermaphrodite. A flower which has only the male parts (androecium) or female parts (gynaecium) is described as **unisexual**. When both male and female flowers occur on the same plant, the plant is described as **monoecious**, e.g. maize, castor oil plant. Plants are described as **dioecious** when male and female flowers occur on separate plants, e.g. pawpaw.

A flower is complete when all the four whorls of floral leaves are present. It is incomplete if one or more whorls of floral leaves are absent.

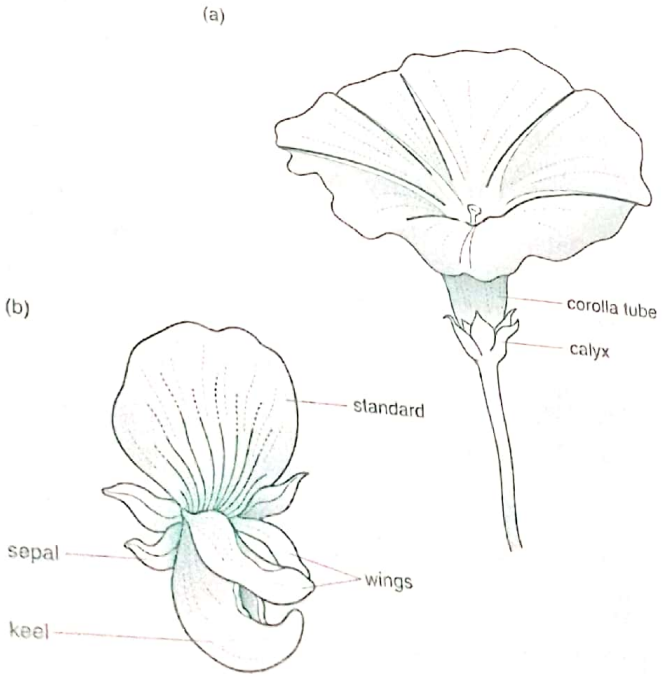


Fig 1.63 The symmetry of flowers (a) radially symmetrical flower of *Ipomoea* sp. (b) bilaterally symmetrical flower of *Crotalaria*.

ACTIVITY 1 Examining flower structure

1 Collect flowers of *Hibiscus* sp., *Caesalpinia pulcherrima* (pride of Barbados), *Delonix regia* (flamboyant), *Crotalaria retusa* (rattle box) and male and female flowers of pawpaw.

2 a) Carefully examine the flower of pride of Barbados.
b) How many floral leaves are present in each whorl?
c) What is the sex of the flower? Explain your answer.

3 Draw and label a whole flower of pride of Barbados and compare it with Figure 1.60..

4 a) Using a sharp razor blade, cut the flower longitudinally into two equal halves.
b) Draw and label one half of the flower and compare it with Figure 1.60.
c) What are the functions of each part of the flower?
d) What is the symmetry of the flower? Explain your answer.

5 Repeat steps 2 to 4 for the other flowers.

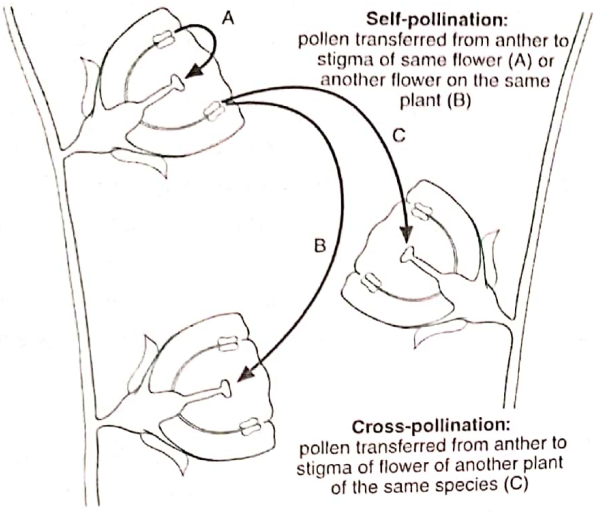


Fig 1.64 Pollination.

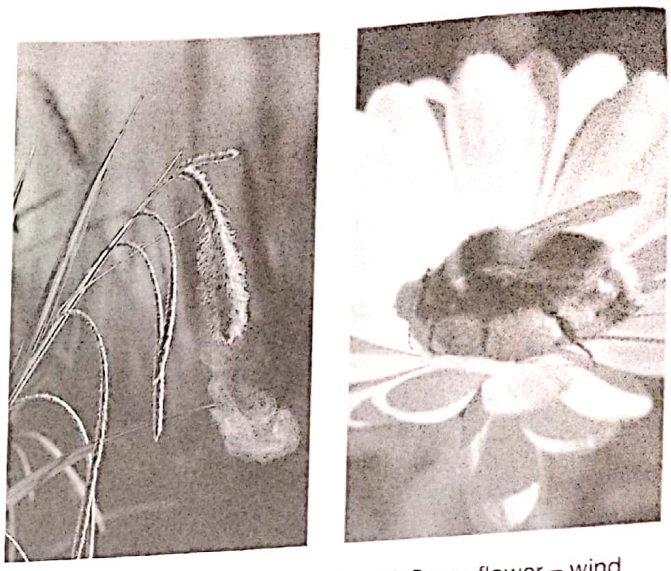


Fig 1.65 Agents of pollination **(a)** Grass flower – wind pollination **(b)** French marigold flower – insect pollination.

Pollination

Pollination is the process in flowering plants by which pollen grains are transferred from the anther to the stigma of a flower. There are two types of pollination: **self-pollination** and **cross-pollination** (Figure 1.64).

- Self-pollination is the transfer of pollen grains from the anther of a flower to the stigma of the same flower or to the stigma of another flower on the same plant. It therefore involves only one parent plant.
- Cross-pollination is the transfer of pollen grains from the anther of one flower to the stigma of a flower on another plant of the same species. It therefore involves two separate plants.
- Some flowers have adaptations for either self- or cross-pollination.

Self-pollination:

- The flower is bisexual or hermaphrodite, i.e. the male *and* female parts are present in the same flower, e.g. pride of Barbados, flamboyant.
- The anthers and stigmas mature at the same time (**homogamy**), e.g. tomato.
- The flower opens only after self-pollination has taken place (**cleistogamy**).
- The flowers are concealed in the ground, e.g. some species of *Commelina*.

Cross-pollination:

- The flowers are unisexual, i.e. only the male *or* female part is present in each flower and both flowers occur on the same plant. The plant is then described as monoecious, e.g. maize or oil palm.
- The plant is dioecious, i.e. male and female flowers occur on separate plants, e.g. pawpaw.
- Each flower is bisexual, but the male and female parts mature at different times – **dichogamy**. The anthers may mature before the stigmas – **protandry**, e.g. cowpea, bleeding heart, or the stigmas may mature before the anthers – **protogyny**, e.g. sunflower, *Tridax*.
- Each flower is self-sterile, i.e. pollen grains cannot fertilise their own flowers, e.g. passion flower.
- The style of the gynaecium and the filaments of the androecium differ in length – **heterostyly**, e.g. long style and short filaments or vice versa. Pollen grains cannot therefore reach the stigma of the same flower.

Certain factors known as agents of pollination are responsible for transferring the pollen grains. These include insects, birds, bats, wind and water. Insects and wind are the major agents because flowers of many plant species are pollinated by one or the other (Figure 1.65).

Adaptations of flowers for pollination

Flowers are adapted in specific ways for the various agents of pollination. Adaptations of flowers for insect and wind pollination are compared in Table 1.32.

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Table 1.32 Comparison of adaptations of insect pollinated and wind pollinated flowers

Insect pollinated flowers	Wind pollinated flowers
large and conspicuous	small and inconspicuous
petals brightly coloured	petals dull in colour
scented	not scented
petals have a nectary, a gland that produces nectar	petals have no nectary
small, compact stigma enclosed in the flower	large, feathery stigma hanging outside the flower
produce large, rough, heavy pollen grains	produce small, smooth, light pollen grains
produce small quantities of pollen grains	produce large quantities of pollen grains
stamens have short, thick filaments and small anthers, not swinging freely in the air	stamens have long, thin filaments with the anthers swinging freely in the air

ACTIVITY 2 Investigating adaptations of flowers for pollination

1 Collect flowers of various plant species, e.g. flamboyant, pride of Barbados, *Crotalaria retusa*, maize, elephant grass, cowpea, castor oil, pawpaw, bleeding heart, sunflower, *Tridax*.

2 Using a hand lens, carefully observe the features of each flower and state, with reasons, which flowers are likely to be:
   a) self-pollinated or cross-pollinated.
   b) insect pollinated, wind pollinated or bird pollinated.

PROJECT 1 Observing pollination in the locality

1 In groups, go out into your locality and observe insects and birds pollinating flowers.

2 Write a short report on your observations, including the names of the flowers, the location of pollination (e.g. in the home, in the field, etc.), the names of agents of pollination (e.g. birds, insects, etc.), the time of the day when pollination occurs and factors which promote or prevent pollination.

3 Do you observe any animals visiting flowers of elephant grass or maize plants?

4 What agent pollinates flowers of elephant grass and maize plants?

Fertilisation

Pollination is followed immediately by fertilisation. Fertilisation occurs in the **ovule**, which contains a female gamete called the **ovum** (egg cell). When a mature **pollen grain** is deposited on a mature stigma, it absorbs water and nutrients from the stigma and swells. The nucleus of the pollen grain divides into two nuclei of unequal size. The larger one is called the **generative nucleus** and the smaller one, the **vegetative** (pollen tube) **nucleus**. The wall of the pollen grain splits and a pollen tube protrudes from it. The **pollen tube** then penetrates the stigma and grows through its tissue into the style. The pollen tube nucleus moves to the tip of the pollen tube, followed closely by the generative nucleus. The pollen tube grows through the style towards the ovary. It derives nutrients from the style and its life processes are controlled by the pollen tube nucleus. As the pollen tube gets closer to the ovary, the generative nucleus divides into two **male nuclei**.

The ovary contains one or more ovules. Each ovule consists of an embryo sac surrounded by two protective coats called the inner and outer **integuments**. There is a small pore called the **micropyle** at one end of the ovule. The end of the ovule opposite the micropyle is called the **chalaza**. The embryo sac contains one ovum (egg) surrounded by two cells called **synergids**, all of which lie at the micropylar end. There are two nuclei called **polar nuclei** at the centre of the embryo sac. There are also three cells, called **antipodal cells**, at the chalazal end of the embryo sac. Another tissue layer called the nucellus lies below the inner integument and surrounds the embryo sac (Figure 1.66). The synergids and antipodal cells do not have any useful function.

The pollen tube enters the ovary and grows towards an ovule. On reaching the ovule, it grows through the micropyle, penetrates the nucellus and enters the embryo sac. The tip of the pollen tube dissolves and the pollen tube nucleus degenerates and disappears. The two male nuclei are then released into the embryo sac. One male nucleus fuses with the egg nucleus to form the **zygote**. The other male nucleus moves to the centre of the embryo sac and fuses with the polar nuclei to form what is called the **primary endosperm nucleus**. This is known as **double fertilisation**. It occurs only in flowering plants.

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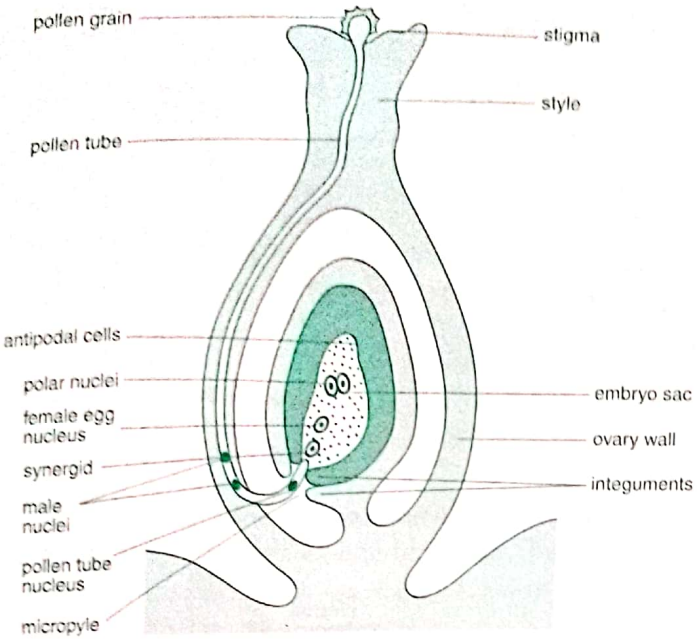


Fig 1.66 Structure of the ovule and fertilisation in flowering plants.

ACTIVITY 3 Observing stages of fertilisation

1 Collect prepared slides showing various stages of fertilisation from your teacher.
2 Carefully examine the slides using a microscope.
3 What stages of fertilisation can you observe?
4 Draw and label these stages.

Fruits

A fruit develops from a fertilised ovary. It contains the seeds, protects them and aids their dispersal. A fruit can be distinguished from a seed by observing the number of scars on its external surface – a fruit has *two* scars on its surface while a seed has *one*. One of the scars of a fruit represents where the fruit was attached to the receptacle. The other scar marks where the style was attached to the ovary. The single scar of a seed marks where it was attached to the ovary wall.

Types of fruit

There are two types of fruit depending on the parts of the flower that form the fruit. These are described as **true fruits** or **false fruits**.

Richmond

A **true fruit** is one which is formed from the ovary of the flower only.

A **false fruit** is one which is formed from the ovary and some other parts of the flower.

Most fruits are true fruits. Examples of true fruits include cowpea, orange, tomato, sunflower, flamboyant, *Crotalaria*, pawpaw. One popular example of a false fruit is that of the cashew plant. The edible 'nut' is formed from the fertilised ovary. The receptacle of the flower becomes enlarged and fleshy, forming a 'fruit' which looks rather like an apple. Figure 1.67 illustrates an apple which is a false fruit.

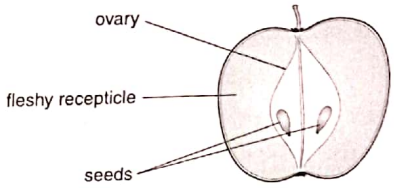


Fig 1.67 Apple – a false fruit.

Fruits are described as simple, aggregate or multiple (compound) depending on the number of flowers that form the fruit (Figure 1.68).

- **Simple fruits** are formed from one flower only with either a single carpel, e.g. cowpea, sunflower, flamboyant, or many fused carpels, e.g. tomato, orange, pawpaw.

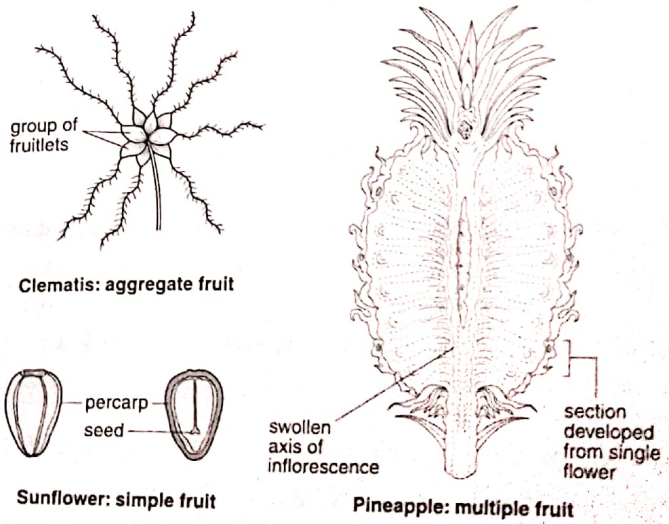


Fig 1.68 Examples of simple, aggregate and multiple fruits.

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- **Aggregate fruits** are formed from one flower which has many free carpels. Each carpel forms a simple fruit called a fruitlet. The aggregate fruit is therefore a collection of fruitlets.
- **Multiple (compound) fruits** are formed from many flowers, e.g. the fig (*Ficus* sp.) or a whole inflorescence, e.g. the pineapple. The ovaries and some other parts of the flower are joined together (fused) after fertilisation to form the fruit. In the pineapple fruit, for example, all the flowers of the inflorescence fuse to form the fruit.

Classes of simple fruits

Simple fruits are either dry or succulent (fleshy).

> In **dry** fruits the pericarp dries out when the fruit ripens.
>
> In **succulent** fruits the pericarp remains juicy and fleshy when the fruit ripens.

Dry fruits are either dehiscent or indehiscent.

> In **dry dehiscent** fruits the pericarp splits open to release the seeds.
>
> In **dry indehiscent** fruits the pericarp does not split open.

Dry dehiscent fruits are classified as legume or pod, capsule, follicle or schizocarp (Figure 1.69).

- **Legume or pod** – formed from a flower which has only one carpel. The fruit has one locule (a space in the fruit in which the seeds are found). Many seeds are arranged along one margin of the fruit. The fruit splits longitudinally along two opposite lines of weakness (sutures) to release the seeds, e.g. cowpea, *Crotalaria*, pride of Barbados, flamboyant.
- **Capsule** – formed from a flower which has many fused carpels. The ovary has many locules containing many seeds arranged on the placenta at the centre. The pericarp may split longitudinally along many sutures to release the seeds, e.g. cotton, okro, or by a ring of holes around the top, e.g. poppy.
- **Follicle** – formed from a flower which has only one carpel. The fruits have only one locule which may contain only one seed, e.g. *Cola*, or many seeds, e.g. *Cnestis*. The pericarp splits longitudinally along only one suture to release the seeds.
- **Schizocarp** – formed from a flower which has only one carpel. The fruits have many separate locules arranged end to end. Each locule contains one seed. The fruit breaks transversely into separate parts with each part containing one seed, e.g. *Desmodium*, *Cassia*.

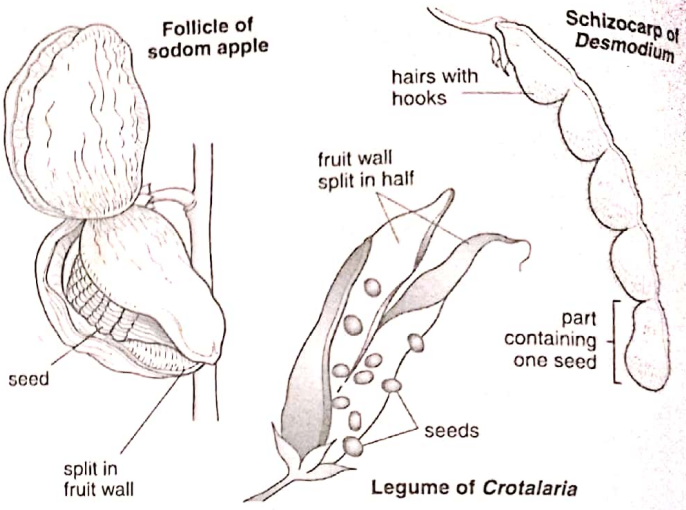


Fig 1.69 Examples of dry dehiscent fruits.

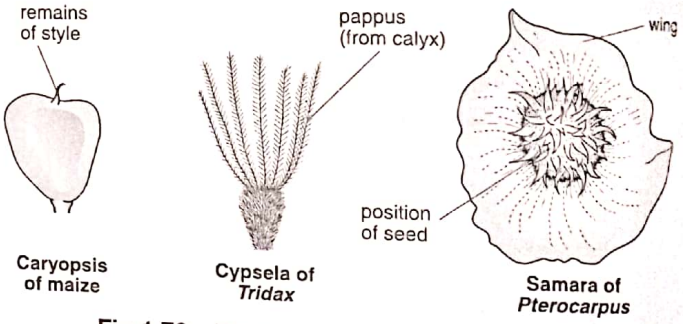


Fig 1.70 Examples of dry indehiscent fruits.

Dry indehiscent fruits are classified as achene, cypsela, caryopsis, samara or nut (Figure 1.70).

- **Achene** – formed from a flower which has one carpel with one locule containing a single seed attached at the base, e.g. sunflower.
- **Cypsela** – like the achene, but the calyx persists and becomes modified to form a parachute-like structure of hairs called a **pappus**. The pappus aids wind dispersal, e.g. *Tridax*.
- **Caryopsis** – also like the achene, but the seed coat and the fruit coat are fused, e.g. maize grain.

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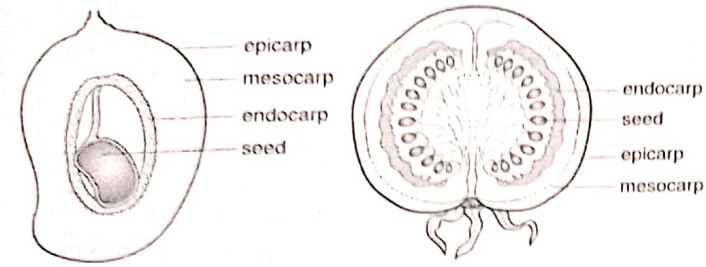


Fig 1.71 Some examples of succulent fruits.

- **Samara** – another achene-like fruit, but the fruit coat is extended to form wings for wind dispersal, e.g. *Combretum*, *Pterocarpus*.
- **Nut** – like the achene, but the fruit coat is very hard and tough, e.g. the hard, kidney-shaped part of the cashew fruit.

Classes of succulent (fleshy) fruits

The pericarp of succulent fruits consists of three layers: an outer epicarp, a middle mesocarp and an inner endocarp. Part or all of the pericarp is fleshy and can be eaten by animals including humans.

Succulent fruits are classified as berries or drupes (Figure 1.71).

- **Berry** – a thin, leathery epicarp, a fleshy mesocarp and a thin, fleshy endocarp. There are many carpels. The fruit contains many locules separated by cross-walls called septa (singular: septum). A berry contains many seeds attached to the placenta at the centre of the fruit, e.g. tomato, guava, pepper. In the fruit of the orange the epicarp and mesocarp are fused.
- **Drupe** – a thin epicarp, a thick, fleshy or fibrous mesocarp and a hard, stony or woody endocarp. There are many fused carpels each enclosing a single locule containing a single seed attached at the base. One example is the mango fruit. It has a thin, leathery epicarp, a thick, fleshy mesocarp and a woody endocarp that encloses and protects the single seed. The epicarp and mesocarp are edible. Another example is the coconut fruit. It has a thin, tough epicarp, a thick, fibrous mesocarp and a stony endocarp. No part of the pericarp of the coconut fruit is edible.

ACTIVITY 4 Examining different types of fruits

1. Collect fruits from different plants in your locality.
2. Carefully examine the external features (and internal features where necessary) of each fruit.
3. Classify each fruit as far as possible. Give reasons for your classification.
4. Draw one fruit from each class to show the features.

Seed structure

Seeds develop from fertilised ovules. They consist of the following parts:

- **Seed coat** – the seed coat consists of two layers – **testa** and **tegmen**. The testa is formed from the outer integument while the tegmen is formed from the inner integument of the ovule. The seed coat protects the inner parts of the seed. It is permeable to water and gases, such as oxygen.
- **Embryo** – the embryo is a rudimentary plant which consists of three parts – the **plumule** (embryonic shoot), **radicle** (embryonic root) and **cotyledons** (seed leaves). Each cotyledon is attached to the embryo by a stalk. The lower part of the plumule is called the epicotyl and the upper part of the radicle is called the hypocotyl. Elongation of the epicotyl or hypocotyl during germination determines the type of germination. After germination of the seed, the plumule develops into the shoot system while the radicle develops into the root system of the plant. The cotyledon stores food for growth of the embryo. Seeds of **monocotyledons** have only one cotyledon, e.g. maize grain. Seeds of **dicotyledons** have two cotyledons, e.g. cowpea, castor oil. The cotyledons also enclose and protect the other parts of the embryo.
- **Endosperm** (in some seeds only) – the endosperm is a massive tissue in which food is stored, e.g. maize grain, castor oil. Its place and function is taken by the cotyledons in most seeds.

Seed of cowpea (*Vigna unguiculata*)

The cowpea is a dicotyledonous, kidney-shaped seed about 1 cm long. It does not have an endosperm. The colour of the seed coat varies from brown, white, red,

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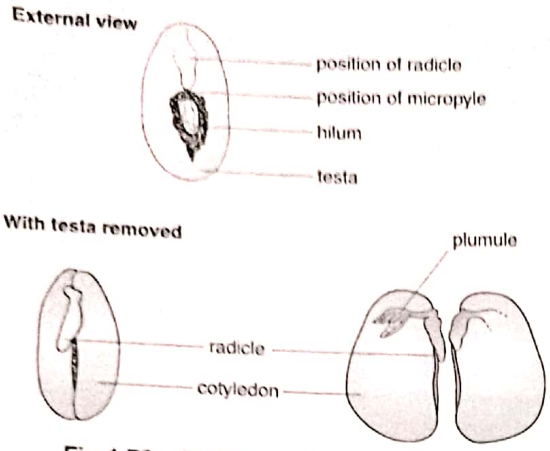


Fig 1.72 Structure of a cowpea seed.

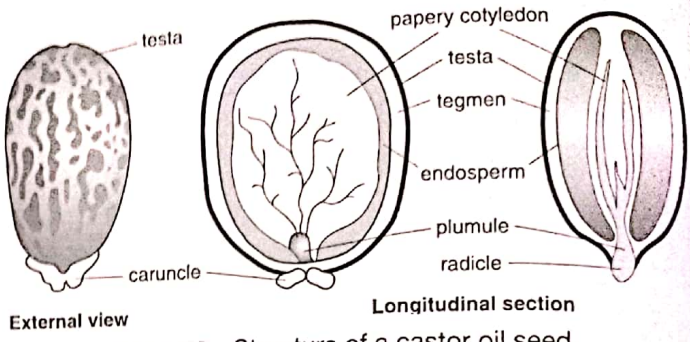


Fig 1.73 Structure of a castor oil seed.

yellowish to black. At one side of the seed is a whitish scar called the **hilum**. This marks where the seed was attached to the ovary wall. The area of the seed coat that surrounds the hilum is darker in colour than the rest of the seed coat. There is a bulge above the hilum in which the radicle lies, called the radicle pocket. A small opening called the micropyle lies at the tip of the radicle pocket. This can clearly be seen by gently squeezing a soaked seed. A droplet of water is then seen coming out from the micropyle.

When the seed coat is peeled off, the two thick, fleshy, whitish cotyledons can be seen, and the radicle. The cotyledons store food, mainly proteins and carbohydrates. They enclose and protect the delicate plumule which lies between them. The leaves of the plumule and their veins are clearly visible (Figure 1.72).

Seed of castor oil

This is a dicotyledonous, oval seed having an endosperm. The seed coat is multicoloured, grey and black in some varieties and black and brown in others. A spongy knob called the caruncle is attached to one end of the seed. This absorbs moisture during germination. A white mass of endosperm covered by the thin tegmen is seen if the hard testa is removed. The endosperm stores oil.

The two thin, flat, oval cotyledons lie face to face with a network of veins in them. There is a short peg-like radicle which projects from the base of the cotyledons and a short, pointed plumule enclosed and protected by the two cotyledons (Figure 1.73).

Grain of maize

A maize grain is actually a fruit, not a seed. It has two scars. One is the remains of the stalk which attached the grain to the central column of the maize cob. The other scar is the remains of the style. The maize grain is yellowish in colour and has two flat sides. It has a shield-shaped white patch called the **scutellum** at one of the flat sides. A ridge which marks the position of the embryo runs down the scutellum.

Internally, the embryo lies just below the fused pericarp and seed coat. The plumule consists of several very small leaves at their youngest stage of development. These are folded around the growing point of the young stem. The tip of the plumule is protected by a sheath called the **coleoptile**. The radicle is short and blunt and its tip is protected by another sheath called the **coleorhiza**.

The single cotyledon is large and attached to the point where the plumule and radicle join. Almost half of the volume of the grain is occupied by the single cotyledon. The rest is occupied by the endosperm, which is yellow on the outside and white inside. It stores starch and proteins (Figure 1.74).

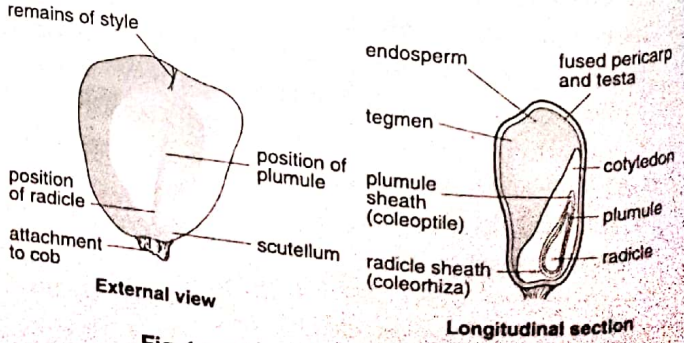


Fig 1.74 Structure of a maize grain.

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ACTIVITY 5 Examining seed structure

1. Collect a cowpea seed, a castor oil seed and a maize grain.
2. Carefully examine their external features.
3. Using Figures 1.72–1.74 as a guide, draw and label the external parts of each seed.
4. Soak them in water for 12 hours.
5. Remove them from the water and cut them.
6. Draw and label the cut surface of each seed.
7. Identify each seed with the name of the collector and date of collection.
8. List the differences in size, shape and colour of the seeds.
9. *Work in groups* to discuss the functions of the parts of each seed.

Dispersal of fruits and seeds

The main functions of fruits are to protect the seeds and aid their dispersal.

Dispersal is the removal and scattering of fruits and seeds away from their parent plants to other places.

In most species the fruits containing the seeds are dispersed, but in others only the seeds are dispersed. Dispersal is important to plants because it:

- prevents overcrowding of seedlings
- reduces competition for light and soil nutrients among seedlings
- prevents the parent plant from shading out its seedlings
- enables plants to colonise new localities, since they cannot move from place to place on their own
- reduces the spread of epidemic diseases likely to occur among crowded seedlings
- enhances the chances of survival of the species, since disasters such as floods and fire that destroy plants in one locality may not occur in another locality.

One disadvantage of dispersal is that the fruit or seed may be carried to an area where conditions are not favourable for the plant to become established. Another disadvantage is that dispersal in most plant species involves external agents which may not be available at the right time.

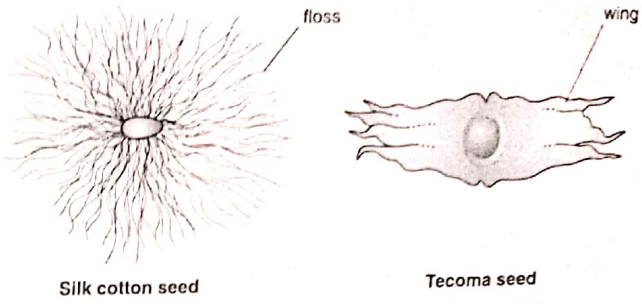


Fig 1.75 Fruits and seeds dispersed by wind.

Dispersal of most fruits and seeds is brought about by certain factors known as **agents of dispersal**. They include wind, animals and water. Fruits of some plants disperse the seeds themselves by methods known as explosive mechanisms (self-dispersal).

Wind dispersal

Fruits and seeds dispersed by wind develop certain features which make them light and easily carried away from their parent by air currents (wind). There are two main types of adaptation. These are:

- small, light seeds, such as those of orchids, which float passively in air and are blown away from the parent plant by the wind
- fruits and seeds with floss, wings or pappus – seeds of cotton and silk cotton plants have a mass of silk threads on the seed coat called floss; seeds of *Tecoma* and Dutchman's pipe have their seed coat flattened to form wing-like structures; *Combretum* has winged fruits; the fruit of *Tridax* has a parachute-like tuft of hairs called a pappus, formed from the persistent calyx of its flower.

These features increase the surface area of the seeds or fruits without adding much to the mass, helping them float in the air and giving resistance to falling so that they fall slowly (Figure 1.75; see also Figure 1.70). When they eventually fall to the ground they may have been carried a long distance away from the parent plant by the wind.

Animal dispersal

Animals which disperse fruits and seeds include birds, monkeys, bats, humans and other mammals. Animal dispersed fruits either have succulent and edible parts, except for the seeds, or have features that attach them to

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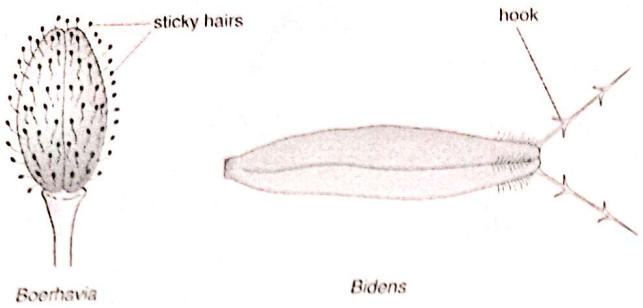


Fig 1.76 Fruits dispersed by animals.

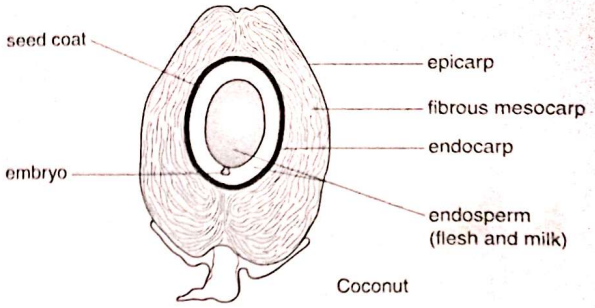


Fig 1.77 Dry cocnut fruit.

the fur and skin of animals or people's clothes (Figure 1.76; see also Figures 1.69 and 1.71).

- **Edible fruits** – the leathery epicarp and fleshy mesocarp of the mango fruit are eaten by animals. The hard endocarp enclosing the seed is not eaten. It is left somewhere away from the parent plant by the animal. The whole fruit of tomato, pawpaw or guava is eaten by animals. The seeds, however, have a fibrous seed coat which resists digestion by the animal's digestive enzymes. The seeds, therefore, pass out undigested in faeces. Edible fruits are usually large, brightly coloured and scented to attract animals.
- **Fruits and seeds with hooks** – fruits of some plants, e.g. *Desmodium*, have hooks on the fruit coat. The seed of *Pupalia* has hooks on the seed coat. These become attached to the fur of mammals and clothing of humans by the hooks. They are later brushed off elsewhere.
- **Fruits with sticky hairs** – fruits of *Boerhavia* and *Plumbago* have sticky hairs on the fruit coat by which they also become attached to fur, skin or clothing and are brushed off elsewhere.

Water dispersal

The dry coconut fruit is adapted for dispersal by water. It has a thick, fibrous mesocarp which contains air spaces between the fibres (Figure 1.77). This reduces its relative density. It therefore floats passively in water and is carried by wave and water currents to distant places. The dry coconut fruit has the ability to float in water for a long time, but can still germinate when the fruit is washed ashore.

The seed of the white mangrove, *Avicennia nitida*, has a spongy seed coat containing numerous large air spaces. This reduces the relative density of the seed. It therefore floats in water and is dispersed in the same way as the coconut fruit. On reaching land away from the parent plant, the seed germinates and grows into a new plant.

Dispersal by explosive mechanisms (self-dispersal)

This method of dispersal involves mechanical splitting of fruits, scattering the seeds away from their parent plants. One way by which seeds are dispersed by explosion is the unequal drying of the fruit coat. While some parts of the fruit coat are dry, other parts are still fresh. This creates tension. The fruit splits open suddenly and violently with an explosive noise, catapulting the seeds away from the parent plant. This mechanism usually occurs in dry weather. Some legumes, such as cowpea, pride of Barbados, *Crotalaria* and flamboyant, show this method of seed dispersal.

An explosive mechanism of seed dispersal may also be caused by turgidity of the fruit coat. In balsam plants, for example, the fruit coat becomes more and more turgid as the fruit becomes ripe. At a certain level of turgidity the fruit suddenly splits open along longitudinal lines of weakness. The split sections suddenly curl inwards and the seeds are hurled out away from the parent plant (see Figure 1.69).

ACTIVITY 6 Investigating dispersal mechanisms of fruits and seeds

1. Move around your locality and collect fruits and seeds of various plants such as cowpea, *Crotalaria,* pride of Barbados, *Combretum*, *Tecoma*, *Tridax*, cotton, silk cotton, coconut, mango, orange, *Desmodium*, *Boerhavia*, Dutchman's pipe, pawpaw, guava, flamboyant, tomato, balsam, *Pupalia*.
2. Carefully examine each fruit and seed and state its method of dispersal as animal, wind, water or self.
3. Make large, labelled drawings of one example from each group to show the adaptations for each method of dispersal.
4. *Work in groups* to discuss the advantages and disadvantages of fruit seed dispersal.

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Seed germination

After their dispersal, seeds may either germinate immediately or undergo a state of dormancy.

Germination is the emergence of the embryo from the seed coat due to onset of growth and development of the seed.

A seed can only germinate if it is viable and the following environmental factors are available:

- moisture
- oxygen
- a suitable temperature.

Some seeds, such as tobacco seeds, also need exposure to light before they can germinate. These environmental factors are known as the conditions for seed germination.

During germination the seed first absorbs water through the seed coat and micropyle. The seed coat becomes soft and the seed swells. Some enzymes in the seed digest the food stored inside the cotyledons or endosperm. The end products of digestion are translocated to the embryo, which uses them to grow. Pressure set up on the seed coat by the absorbed water and the growing embryo causes the seed coat to split open. As the embryo grows, it emerges from the seed coat, the radicle first, followed by the plumule. The young plant is called a seedling.

Types of germination

There are two types of germination, depending on the position of the cotyledons:

- **Epigeal germination** occurs when the cotyledons appear above the ground. It is caused by elongation of the hypocotyl of the radicle during germination, e.g. cowpea (Figure 1.78a).
- **Hypogeal germination** occurs when the cotyledons remain below the ground. It is caused by elongation of the epicotyl of the plumule, e.g. maize grain (Figure 1.78b).

Dormancy

Dormancy is a resting stage during which growth stops temporarily and metabolism is reduced to its barest minimum.

A seed is described as dormant when it fails to germinate in the presence of all the conditions for germination.

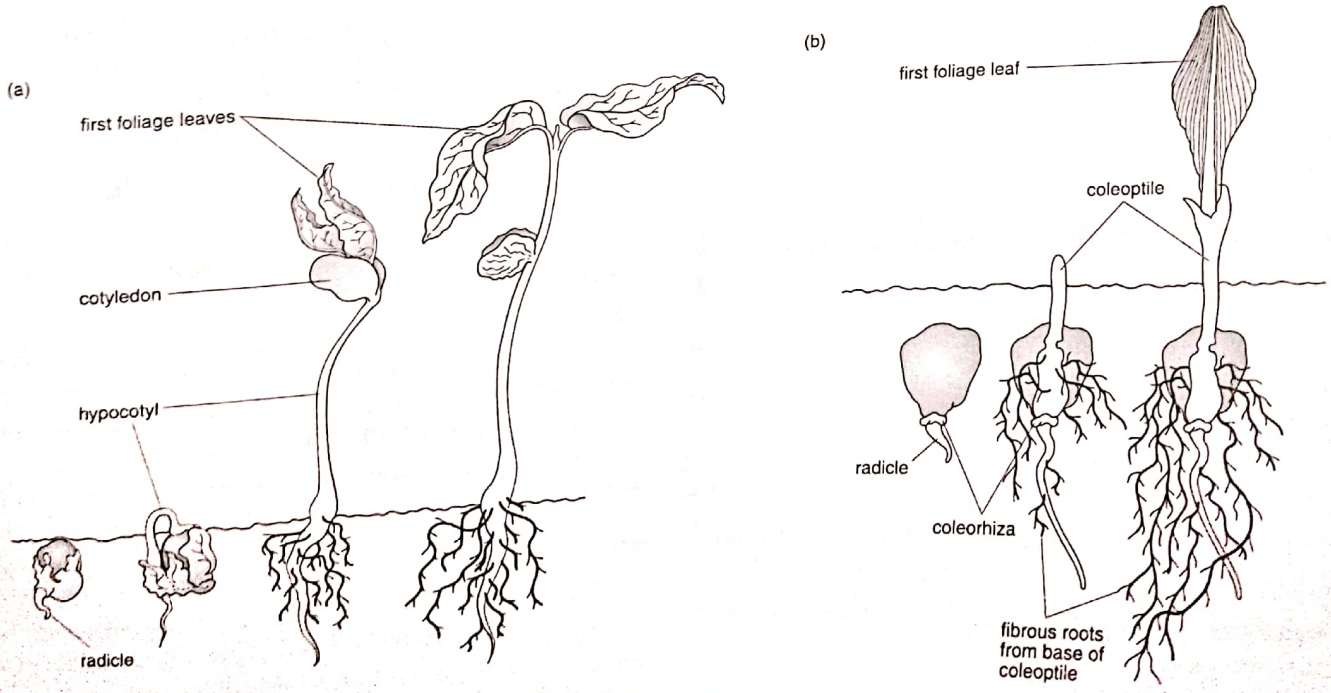


Fig 1.78 Stages in germination of **(a)** cowpea (epigeal) **(b)** maize grain (hypogeal).

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Dormant seeds may survive adverse conditions, such as drought, floods, low or high temperatures.

ACTIVITY 7 Investigating conditions for germination

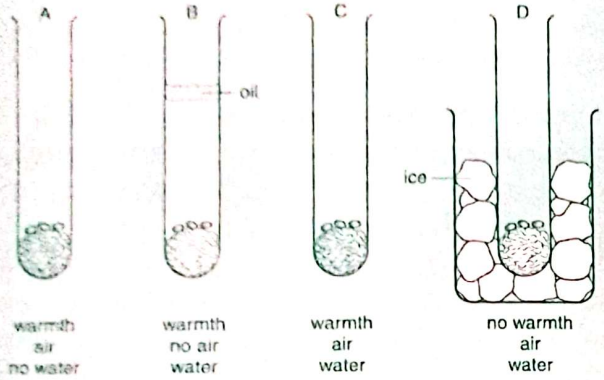


Fig 1.79 Conditions for seed germination.

1 Set up four test tubes and label them A, B, C and D as shown in Figure 1.79. Use *Crotalaria* or other small seeds.
2 Why is boiled, cooled water used in test tube B?
3 What is the purpose of the layer of oil in tube B?
4 What environmental conditions are available in each tube and what are not available?
5 Observe the test tubes regularly for 7 days.
6 In which tubes did the seeds germinate?
7 Under which conditions do seeds germinate?

ACTIVITY 8 Investigating types of germination

1 Collect seeds of cowpea, groundnut and pepper, and grains of maize and Guinea corn.
2 Sow several of each seed or grain in well watered soil.
3 Observe daily for 7 days using Figure 1.78 as a guide.
4 Which seeds or grains show:
a) epigeal germination?
b) hypogeal germination?
5 Use diagrams to explain the difference between epigeal and hypogeal germination.

Asexual reproduction (vegetative propagation)

A large number of flowering plants do not produce seeds. Instead, these plants reproduce from vegetative parts such as stems, leaves or roots. Many of these plants have modified underground stems. Examples include rhizomes, bulbs, corms and suckers. Underground stems, like roots, are non-green but have features of stems including buds, scale leaves (reduced, non-photosynthetic leaves) and fibrous and adventitious roots.

Rhizome

This is a thick, whitish modified stem that grows horizontally underground. The stem is enclosed by brown scale leaves. It has a terminal bud that develops into an aerial shoot. Lateral (axillary) buds in the axils of the scale leaves develop into stem branches. The stem stores food. Adventitious roots develop from the nodes. Examples include ginger and canna lily (Figure 1.80).

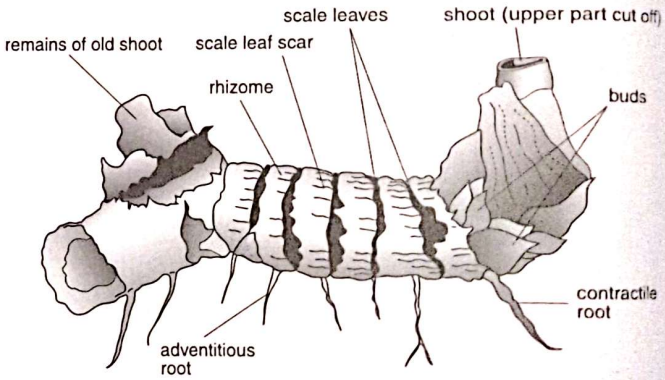


Fig 1.80 Rhizome of canna lily.

Rhizomes can be propagated vegetatively by stem cuttings. The rhizome is cut into pieces, each piece having two to three buds. The pieces are planted in soil and watered regularly. The buds sprout and grow into new aerial shoots a few days after planting. The whole rhizome can also be planted.

Bulbs

A bulb has a short, brown conical stem which grows vertically underground. It has a terminal bud which develops into an aerial shoot. The leaf bases are modified into scale leaves, arranged in concentric circles

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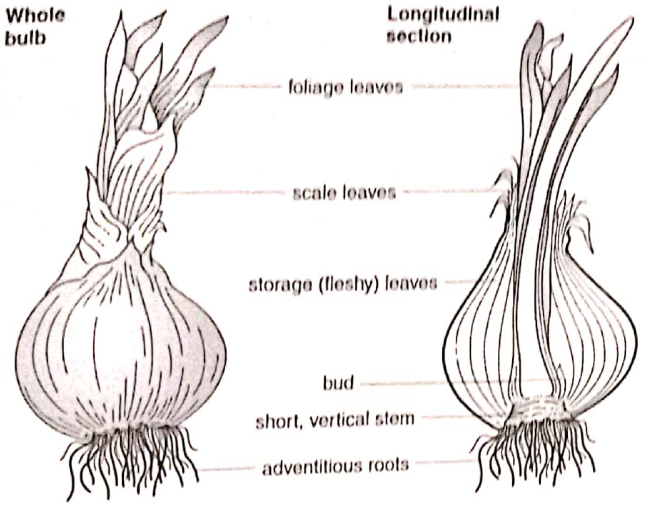


Fig 1.81 An onion bulb.

around the short stem. The outer scale leaves are brown, thin, dry and membranous. They cover and protect the thick, fleshy inner scale leaves which store food. The internodes are very short. Axillary buds in the axils of the fleshy scale leaves develop into daughter bulbs. Numerous fibrous roots arise from the base of the short stem. Examples include spider lily and onion (Figure 1.81).

Bulbs are propagated vegetatively by planting the whole bulb in well-manured soil. The axillary buds then develop into daughter bulbs underground, thereby multiplying the plant. Some types of onion produce seeds from which new plants develop when planted in soil. A bulb may also be left in a moist place. After a few weeks its axillary buds sprout into young bulbs. These are then separated and planted individually in soil.

Corm

A corm is a short, compressed, modified stem surrounded by brown scale leaves. It grows vertically underground. The stem has long internodes and adventitious roots arise from the nodes. A terminal bud gives rise to an aerial shoot. Axillary buds develop in the axils of the scale leaves. These form daughter corms. The stem is thick with stored food.

Corms may be propagated vegetatively by cutting the whole corm into pieces such that each piece has a number of buds. Each piece is then planted singly in soil. The whole corm can also be planted in soil, after which the axillary buds develop into daughter corms. Some examples of corms are *Caladium* sp., cocoyam, *Gladiolus* sp. and *Colocasia* sp. (Figure 1.82).

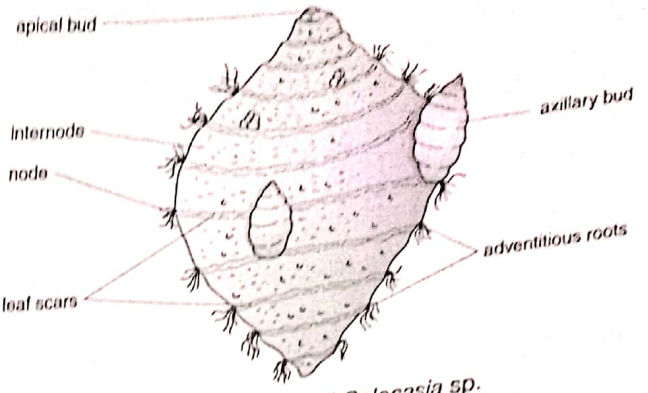


Fig 1.82 A corm of *Colocasia* sp.

Sucker

A sucker is a lateral outgrowth from the underground part of the stem of certain plants. The stem of a sucker bears a terminal bud, adventitious roots and scale leaves. The tip of the stem bends upwards and appears above the soil level. It then gives rise to the aerial shoot. A sucker does not store food but depends on the parent plant for nourishment. Plantain and banana are common examples of plants that produce suckers (Figure 1.83).

A sucker may be propagated vegetatively by carefully cutting the young sucker close to the parent's stem. The young plant is then carefully uprooted and transplanted in soil.

Runner

A runner is a thin, creeping stem which grows horizontally along the surface of the ground. The stem has long internodes and produces adventitious roots at its nodes. These roots penetrate the soil and fix the weak stem firmly to the soil surface. Aerial shoots develop from the nodes opposite the adventitious roots. Examples of plants with runners include sweet potato and *Desmodium* (Figure 1.84).

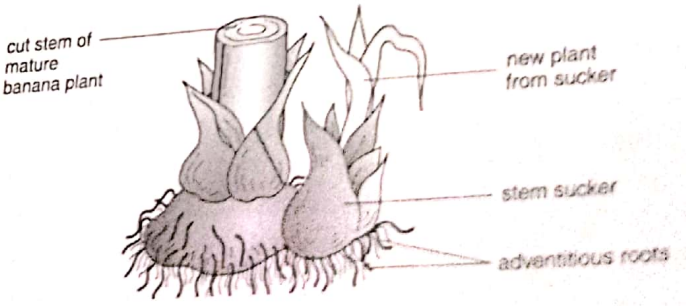


Fig 1.83 A sucker of banana.

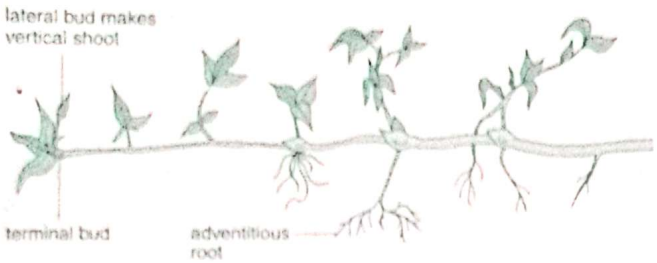


Fig 1.84 A runner of *Desmodium*.

To propagate a runner vegetatively, the stem is cut into pieces, with each piece having at least two nodes. One end of the piece of stem is pushed into the soil. The buds at the nodes sprout into new plants.

ACTIVITY 9 Examining organs of vegetative propagation

1 Collect an onion bulb, a rhizome of ginger or canna lily, a corm of cocoyam or *Caladium*, a sucker of plantain or banana and a runner of sweet potato or *Desmodium*.
2 Carefully examine the external features (and internal features where necessary).
3 List the features common to all the modified stems above.
4 State how each modified stem differs from all the others, e.g. a rhizome and bulb, a rhizome and corm, a bulb and corm, etc.
5 Draw and label the characteristic features of each type of modified stem.
6 What are the functions of each part labelled?
7 Follow instructions in the text to propagate some of the organs vegetatively.

Artificial propagation

Many flowering plants may be multiplied artificially by stem cuttings, budding, grafting and layering.

Stem cuttings

This can be used for plants that produce flowers but do not form seeds. The stems are cut obliquely (at an angle) just below a node. Each cutting must have three to five nodes. The lower end of the cutting is pushed into the soil with at least one node below the soil surface. Adventitious roots develop from the node in the soil while aerial shoots grow from the nodes above the soil surface (Figure 1.85. Plants propagated vegetatively by

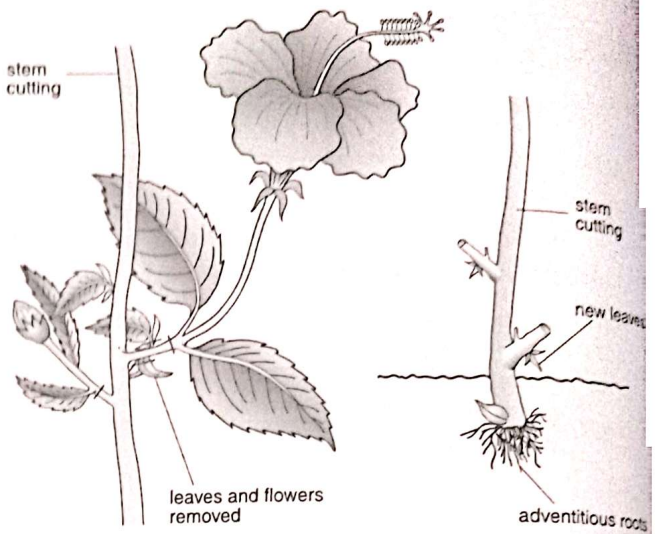


Fig 1.85 Vegetative propagation by stem cuttings.

cuttings include cassava, sugar cane, *Croton*, *Hibiscus* and runners such as sweet potato.

Budding

In budding a dormant bud on a sliver of stem called the **scion** is carefully removed from one plant using a sharp penknife. It is inserted into a T-shaped cut in the bark of another plant called the stock. The stock must have a well-established rooting system. The cambium of the scion is exposed by carefully scraping off the woody part of the stem attached to it. The scion is carefully placed in the T-shaped cut of the stock so that the cambia of the scion and stock make contact (Figure 1.86). The scion and stock are firmly bound together and the area is covered with a waterproof material, such as a polythene bag. The bud on the scion develops and bears the fruits of the plant from which it was removed. This method is used to propagate such plants as citrus trees and roses which have desirable characters but cannot be propagated from cuttings.

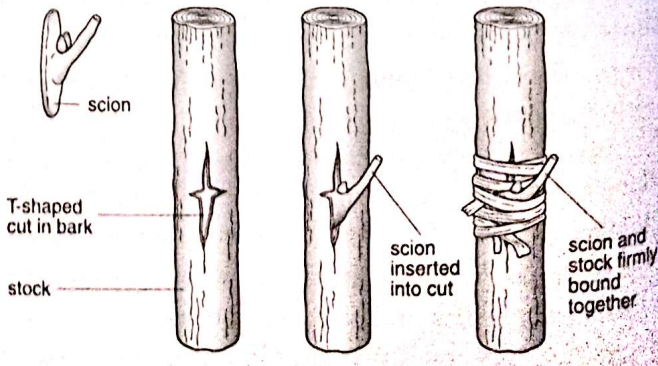


Fig 1.86 Vegetative propagation by budding.

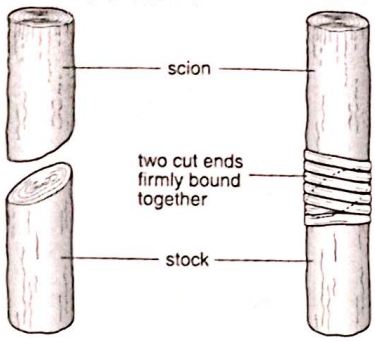


Fig 1.87 Vegetative propagation by grafting.

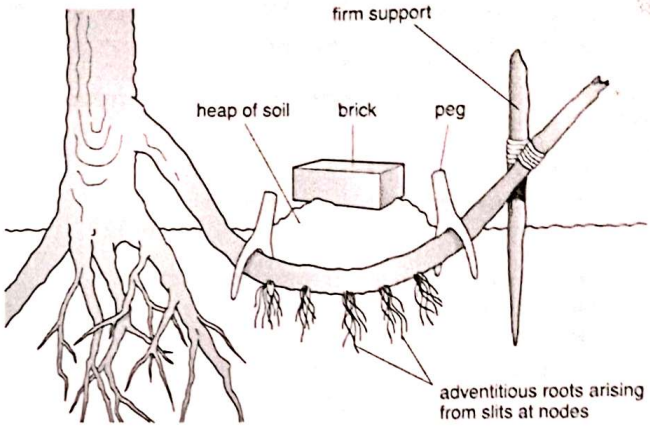


Fig 1.88 Vegetative propagation by layering.

Grafting

Vegetative propagation by grafting involves joining parts of one plant on to another plant of a different variety of the same species. The scion is a short length of stem with at least one bud. It is joined to the cut end of the stem of another plant, the stock. The cambia of the stock and scion must make contact. To achieve this, the scion may be pointed to fit into a V-shaped stock, or slanted to fit a slanting stock. The scion and stock are then bound together. The cuts soon heal and the stock and scion continue to grow as one plant and bear the fruits of the plant from which the scion was removed (Figure 1.87). Grafting is usually done in the peak of the growing season. Some examples of grafting are grapefruit trees and lime trees to orange trees.

Grafting is also used to grow plants which cannot be reproduced from seeds or stem cuttings, e.g. grafting a white-flowered *Bougainvillaea* to a pink or red-flowered one.

Layering

This method of vegetative propagation is used to propagate plants like *Bougainvillaea* and rose that do not produce seeds and will not always grow from stem cuttings either. A branch of the stem close to the ground is carefully bent over so that part of it, having a number of nodes, touches the ground. The end of the branch is tied to a firm support. Using a penknife, a slit is made at a node that touches the ground. This part of the branch is pushed into the soil and held in place with two pegs. It is covered with a heap of fertile soil and a heavy object, such as a stone or block, is placed on top. The soil is watered regularly and dug out from time to time to find out if adventitious roots have developed (Figure 1.88). When roots appear at the slit node, the rooted twig is cut off and transplanted in fertile soil. It is cared for until it becomes a fully established plant.

ACTIVITY 10 Observing artificial propagation of plants

1 Visit local parks and gardens, a nursery or a horticultural centre and observe plants being developed by cuttings, budding, grafting and layering.

2 Find out how long it takes for the propagated part to become established.

3 Find out how long it takes for the propagated part to fully develop and start bearing flowers and fruits.

Differences between sexual and asexual (vegetative) reproduction in flowering plants are summarised in Table 1.33.

Table 1.33 Differences between sexual and asexual (vegetative) reproduction in flowering plants

Sexual reproduction	Asexual reproduction
involves fusion of nuclei of gametes to form zygotes which grow to become the offspring	does not involve fusion of nuclei – zygotes are not formed; vegetative organs such as rhizomes, corms, bulbs, suckers, runners and stem pieces grow to become the offspring
new varieties are reproduced due to mixing of characters of two parents	no new varieties are reproduced as identical characters are repeated over generations
requires two parents unless a parent is a hermaphrodite	requires one parent only

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Self check

For questions 1 to 13, choose the letter that refers to the correct option.

1 A group of petals is known as the:
A androecium B calyx
C corolla D gynaecium

2 Which parts of the flower make up the carpel?
A anther and filament
B ovary, style and anther
C ovary, filament and stigma
D ovary, style and stigma

3 Which of the following parts of the flower produces the female gametes?
A androecium B calyx
C corolla D gynaecium

4 Flowers which have large, feathery stigmas are likely to be pollinated by:
A birds B insects
C water D wind

5 Which of the following adaptations of flowers most favours cross-pollination?
A flower is bisexual
B male and female parts mature at the same time
C male and female flowers are on separate plants
D flowers are buried in the ground

6 After fertilisation the zygote develops into the:
A embryo B endosperm
C seed D seed coat

7 Which of the following fruits is an example of a false fruit?
A cashew B mango
C orange D pawpaw

Use the list of classes of fruits below to answer questions 8 to 10.
I legume (pod)
II achene
III berry
IV capsule
V drupe

8 Which classes of fruits listed above are dry dehiscent fruits?
A II and III
B II and V
C I and IV
D III and V

9 Which classes are dry indehiscent fruits?
A I only
B II only
C I and IV
D I and V

10 Which classes are succulent fruits?
A I and II
B I and IV
C II and IV
D III and V

11 Which of the following underground stems stores food in its leaves?
A rhizome B bulb
C corm D sucker

12 An example of a plant which reproduces vegetatively by suckers is:
A banana B canna lily
C onion D cocoyam

13 Which of the following statements describes a bulb?
A It grows horizontally underground and has long internodes.
B It grows obliquely from an underground part of the parent plant.
C It has fibrous roots arising from the base, a short, conical stem that grows vertically and short internodes.
D It has a thick, horizontal stem and adventitious roots arising from the nodes.

14 a) Name the parts of a flower and state their functions.
b) Give one example of a:
(i) unisexual flower
(ii) bisexual flower.

15 a) Distinguish between self-pollination and cross-pollination.
b) Name the agents of pollination.
c) Tabulate the differences between wind pollinated and insect pollinated flowers.

16 a) Describe the process of fertilisation in a flower.
b) List the changes that occur in a flower after fertilisation.

17 a) Name two classes of:
(i) dry dehiscent fruits
(ii) dry indehiscent fruits
(iii) succulent fruits.
b) Give an example of each class.

18 Describe adaptations of fruits and seeds for:
a) wind dispersal
b) animal dispersal
c) water dispersal.

19 Describe how the explosive mechanism of seed dispersal is brought about in:
a) balsam
b) pride of Barbados.

20 a) Distinguish between a fruit and a seed.
b) State the conditions necessary for seed germination.

21 Describe an activity to establish the conditions necessary for seed germination.

22 Define the following terms, giving two examples of each:
a) hypogeal germination
b) epigeal germination.

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23 **a)** State the external features of the following:
(i) rhizome
(ii) corm
(iii) bulb.
b) Describe the various methods of artificial propagation of plants.

24 Study the diagrams and answer the questions that follow:

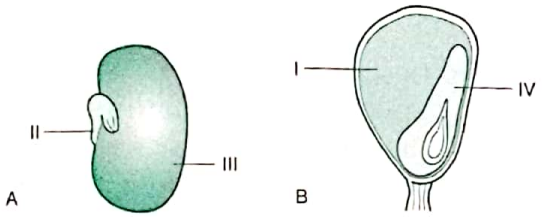


Fig 1.89

a) Identify the type of seed illustrated in A and B.
b) Name the parts labelled I, II, III and IV.
c) Tabulate two structural differences between the two types of seeds.
d) (i) State what would be observed when a drop of iodine solution is added to the part labelled I in B.
(ii) Give reasons for your answer.

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3 Respiratory system

Learning objectives

After studying this unit, you should be able to:

1 define respiration and explain its importance
2 distinguish between aerobic and anaerobic respiration
3 identify the respiratory organs in the respiratory system of a mammal and describe their functions
4 explain the mechanism of inhalation and exhalation in humans
5 enumerate some problems and disorders associated with the respiratory system in humans
6 explain how respiratory gases are taken in and out of plants.

Respiration

Respiration is one of the most important life processes in living things. The energy that humans and all other living things need to move, grow and so on is obtained from respiration. This process normally needs oxygen which combines with organic food, breaking it down and releasing energy to where it is needed in the body.

Every life process has certain problems and disorders associated with it, and respiration is not an exception.

Each cell in your body (and in the bodies of all other organisms) must continuously expend energy to maintain itself. The food we eat contains energy and yet it is not available to the body even after digestion. To unlock this trapped energy in the digested products respiration occurs. Respiration occurs in living organisms in order that they obtain energy from what they eat.

Consider this practical example. When you need your muscles to carry you upstairs quickly, the demands are extreme. As cellular respiration converts the energy in nutrients, such as sugar, into ATP (adenosine triphosphate) that can be used by body cells, the process requires a steady supply of oxygen and generates carbon dioxide as a waste product. The rapid beating of your heart as you relax after the sprint upstairs is a remainder that the circulatory system works in close harmony with the respiratory system, extracting oxygen from air in your lungs to the cells and then picking up carbon dioxide for release in the lungs.

Respiration is therefore defined as the sum total of the chemical processes aided by enzymes that lead to the release of energy from food substances either in the presence or absence of oxygen. Respiration can be external or internal.

- **External respiration** – this is the intake of oxygen and the release of carbon dioxide, utilised gases and water to the external environment. This is known as gaseous exchange.
- **Internal respiration** – this is also known as cellular respiration or tissue respiration. Internal respiration is a series of enzyme-catalysed reactions within the cell in which organic molecules are oxidised to release energy as ATP. It can take place in the presence or absence of oxygen.

Types of respiration

Aerobic respiration

This is the breakdown of glucose in living cells to provide energy in the presence of oxygen:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{(38 ATP)}}{\text{Energy}}$$

raw materials — by-product — main product

Anaerobic respiration

This is the kind of respiration which occurs in some organisms when carbohydrates, usually glucose, are broken down to provide energy in the absence of oxygen. Anaerobic respiration occurs in both plants and animals. In plants ethanol is one of the products of anaerobic respiration.

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$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 +$ Energy (2 ATP)
glucose (substrate) → ethanol (alcohol) + carbon dioxide + Energy (2 ATP)

However, in animals lactic acid instead of ethanol is produced.

$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 +$ Energy (2 ATP)
glucose (substrate) → lactic acid + Energy (2 ATP)

Table 1.34 summarises the differences between aerobic and anaerobic respiration.

Table 1.34 Differences between aerobic and anaerobic respiration

Aerobic respiration	Anaerobic respiration
requires oxygen	no oxygen required
water is provided as a by-product	no water is produced
much energy is released	very little energy is released
no alcohol or lactic acid is produced	alcohol or lactic acid is produced

Alcohol production is possible in beers, gins and wines through anaerobic fermentation of sugars.

Yeasts and some bacterial enzymes break down carbohydrates anaerobically to produce alcohol, carbon dioxide and organic acids which give fermented foods, such as kenkey, banku and yoghurt, their characteristic sour taste.

Importance of respiration

Respiration is important to living organisms because they need energy for their daily activities. Without the supply of energy from the metabolic activities of cells, living organisms will die. This energy comes from the food substances that organisms take into their bodies. The food substances are oxidised or 'burned' in order to release the energy that they contain.

The energy released during respiration is used in many life activities including:

- muscle contraction
- cell division
- heat production, which enables mammals and birds to maintain a constant body temperature
- active transport of substances in and out of cells
- production of chemical substances in cells (biosynthesis), e.g. proteins
- break down of chemical substances in cells (biodegradation), e.g. glucose.

Richmond

ACTIVITY 1 Demonstrating the release of heat energy during respiration of germinating seeds or small animals

1 Your teacher will set up the apparatus as shown in Figure 1.90. The seeds are first washed in disinfectant. The boiled seeds in B are washed in formalin solution after boiling. To demonstrate the release of heat energy by small animals, the germinating seeds in flask A can be replaced by insects (e.g. cockroaches, grasshoppers or millipedes). A control can be set up with an empty flask.

2 **a)** Why are the seeds washed in disinfectant?
b) Why are the boiled seeds soaked in formalin solution?

3 Read the thermometers and record the temperature in each flask at the start of the activity.

Repeat the readings every morning and evening for 1 week.

Note: With the insects, record the temperature every 10 minutes for 1 hour, then release the insects.

4 Record the temperature changes in flask A and flask B in a table.

5 **a)** Which flask is the control?
b) What can you conclude from your results?

The temperature in flask A increases gradually while the temperature in flask B remains more or less the same. It is important to wash the seeds in a disinfectant and soak the boiled seeds in formalin to prevent decay. This is because the microorganisms which cause decay produce heat and so will affect the results.

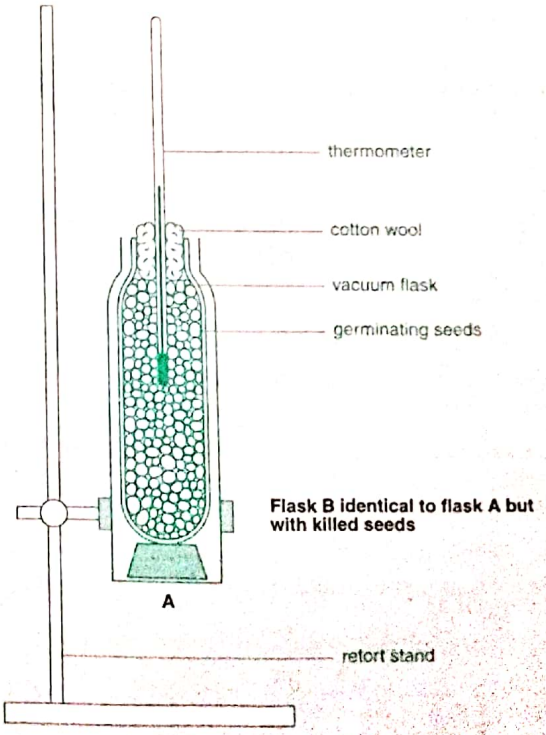


Fig 1.90 Release of heat by germinating seeds.

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ACTIVITY 2 Demonstrating the release of carbon dioxide during respiration of germinating seeds or a small mammal

1 Your teacher will set up the apparatus shown in Figure 1.91. Caustic soda solution absorbs carbon dioxide. Lime water turns from clear to milky when air containing carbon dioxide is bubbled through it.

2 Observe the apparatus, firstly with a small mammal in the bell jar, secondly with a dish of germinating seeds in the bell jar (washed in disinfectant) and, thirdly, with the bell jar empty. Change the lime water in jar B each time.

3 a) Why is jar A necessary?
b) What happened to the lime water in jar B each time?
c) Which part of the activity was a control?
d) What can you conclude from your results?

Jar A proves that there is no carbon dioxide in the air entering the bell jar.

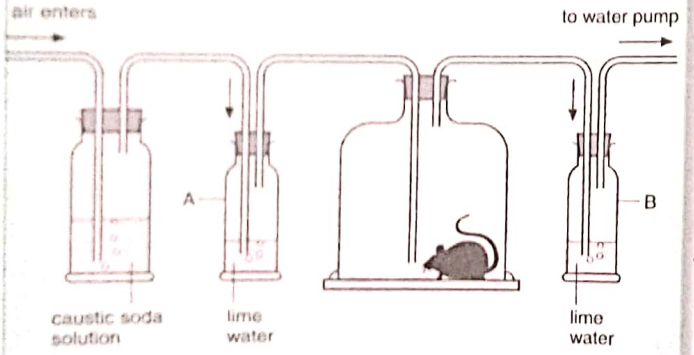


Fig 1.91 Release of carbon dioxide during respiration of a small mammal or germinating seeds.

ACTIVITY 3 Demonstrating the release of heat during yeast fermentation of corn dough

1 Your teacher will set up the apparatus as in Figure 1.92.

2 Read and record the temperature of each flask at the start of the activity.

3 Read the temperature of each flask at 1 hour intervals. Record the changes in temperature in flask A and flask B.

4 a) Which flask is the control?
b) Why are the mixtures in the flasks covered with oil?
c) What can you conclude from your results?

The temperature in flask A increases with time, while the temperature in flask B remains more or less the same. The oil prevents oxygen from getting into the mixture, proving that anaerobic respiration is taking place.

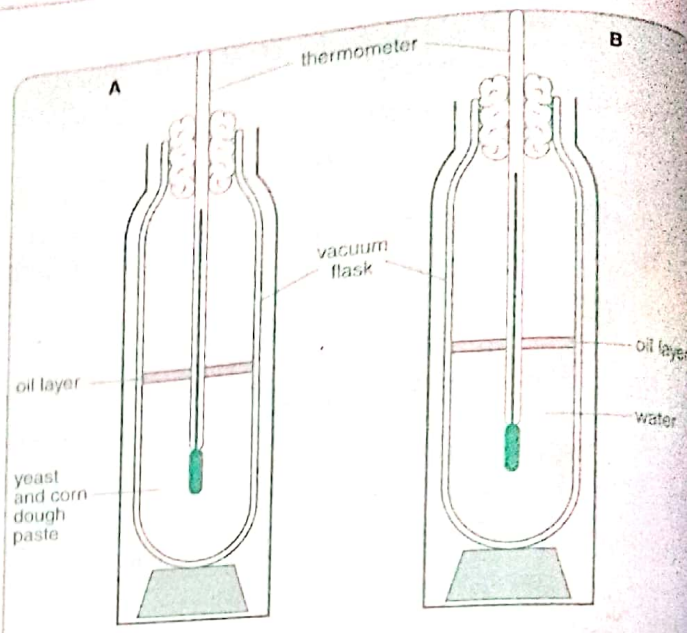


Fig 1.92 Release of heat during yeast fermentation of corn dough.

ACTIVITY 4 Demonstrating the release of carbon dioxide (CO_2) during yeast fermentation

1 Your teacher will set up the apparatus as in Figure 1.93. A second set of apparatus is set up with boiled, distilled water replacing the yeast and corn dough mixture.

2 Observe the two sets of apparatus at 1 hour intervals. Record what you observe in tube A and in tube B.
a) Which tube is the control?
b) What do you conclude from your observations?

Bubbles of gas are seen escaping from the delivery tube into the lime water from tube A. The lime water turns cloudy (milky), an indication that the gas produced is carbon dioxide. The bubbling shows fermentation of the corn dough by the yeast.

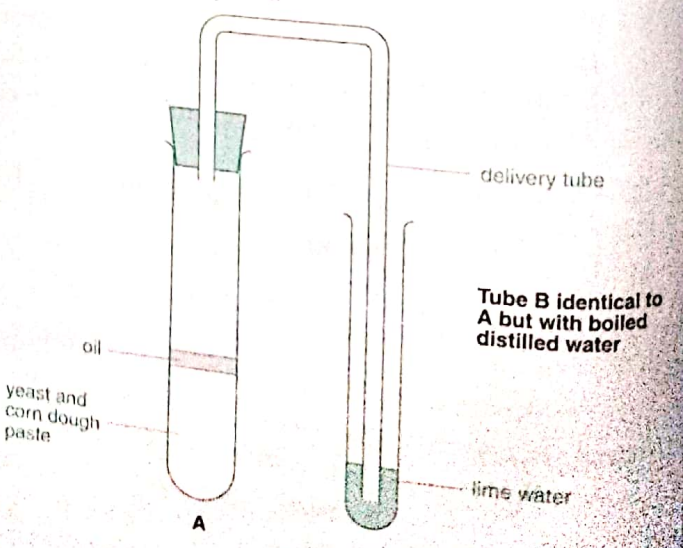


Fig 1.93 Release of carbon dioxide during yeast fermentation.

Structure and function of the respiratory system of mammals

The structures concerned with respiration in mammals, e.g. humans, are two spongy, elastic organs called **lungs** which lie in the thoracic cavity. They lead to the outside air through a series of air tubes. Air enters through the nostrils, then passes through the nasal cavity, the larynx (voice box) into the **trachea** (wind pipe). At the top of the larynx is a flap of tissue called the **epiglottis**. This closes over the larynx during swallowing and prevents food from entering the trachea. The larynx enables humans to talk and sing.

The wall of the trachea is strengthened by incomplete rings of **cartilage** to keep it open. The inner lining of the trachea and the nasal passages are covered with cilia (microscopic hair-like structures) and mucus producing cells. The mucus traps dust particles and microbes in the air and the cilia move the mucus upwards to the throat where it is either swallowed or coughed out. The air passages also warm and moisten the cold, dry air before it enters the lungs. Thus the nasal passages and trachea prevent harmful substances from reaching the lungs (Figure 1.94).

The trachea branches into two tubes called **bronchi** (singular: bronchus), one to each lung. The bronchi, like the trachea, are supported by rings of cartilage, lined with cilia and secrete mucus. The bronchi branch into numerous smaller air tubes called **bronchioles**. Each bronchiole ends in a bunch of small air sacs called

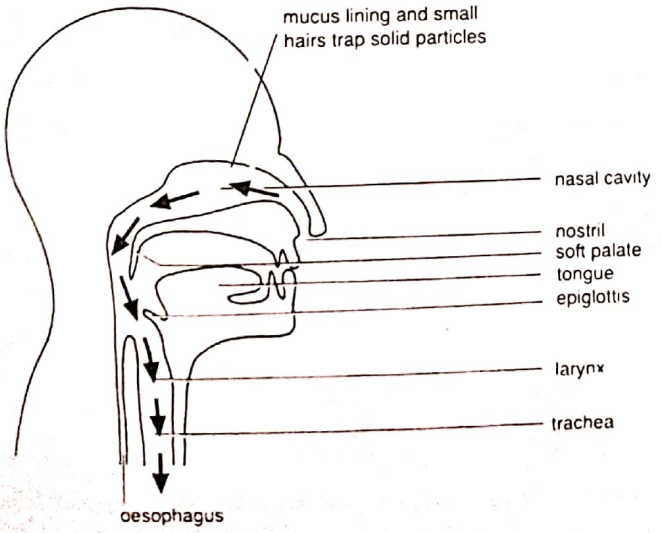


Fig 1.94 The path of air into the lungs.

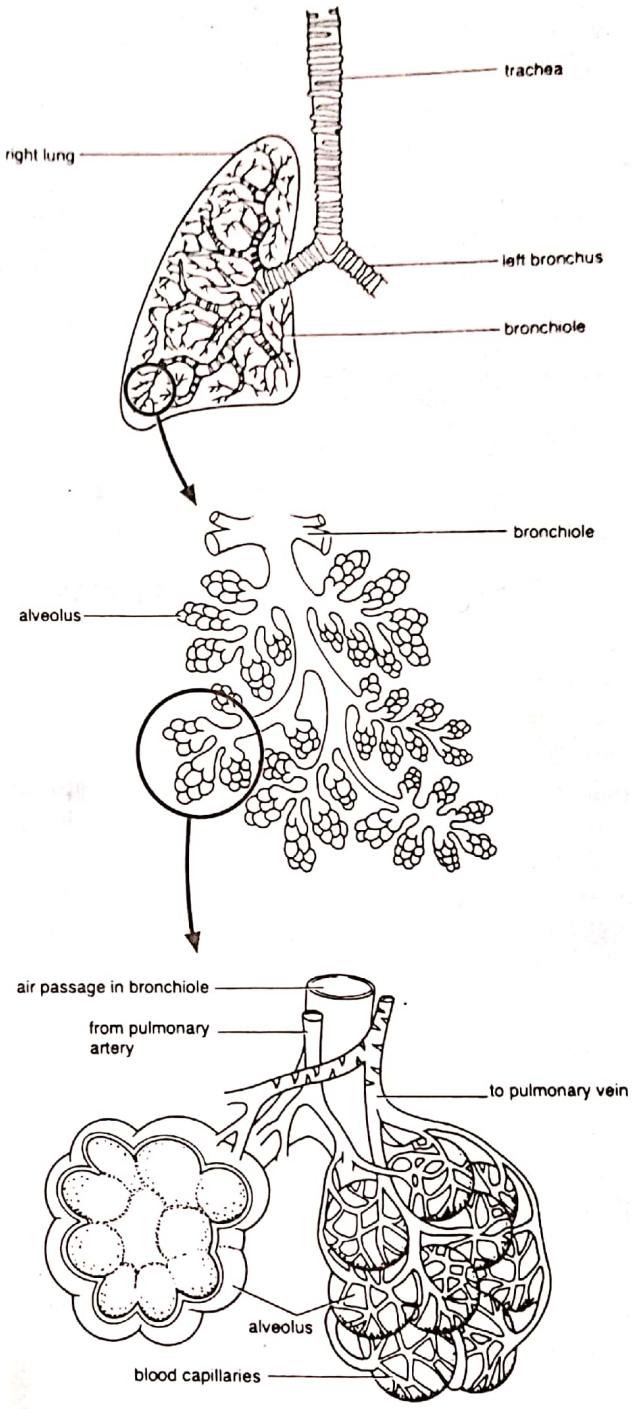


Fig 1.95 The lungs, alveoli and their blood supply.

alveoli (singular: alveolus). The alveoli have a thin wall and a network of blood capillaries surrounding them. Exchange of respiratory gases takes place in the alveoli of the lungs (Figure 1.95).

The thoracic cavity is bounded by the ribs, the sternum and the vertebral column. Between the ribs are

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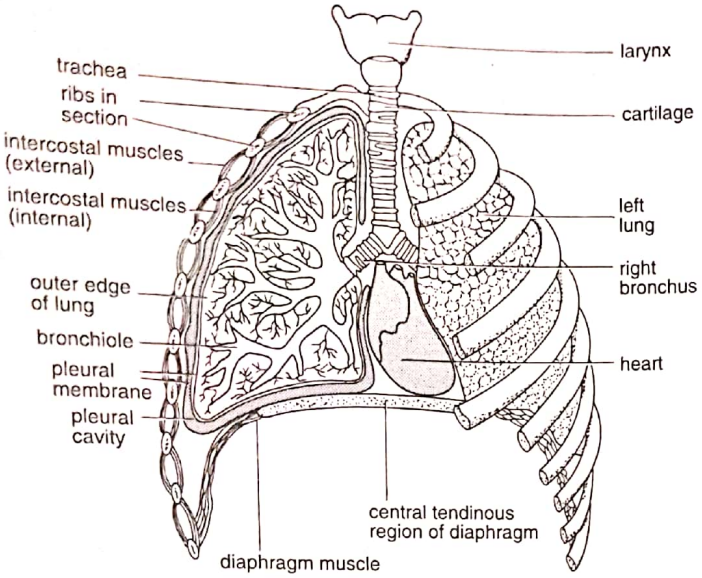


Fig 1.96 The lungs, heart and associated organs.

muscles called **intercostal muscles**. The **diaphragm**, a sheet of muscular tissue, separates the thoracic cavity from the abdominal cavity (Figure 1.96). The intercostal muscles and the diaphragm play a major role in breathing.

ACTIVITY 5 Examining the respiratory structures of a small mammal

1 Your teacher will dissect a rabbit or guinea pig and display the respiratory organs.

2 Examine the dissection. Use Figure 1,96 as a guide to identify the structures.

3 Draw and label the dissection. Use arrows to show the path of air from the atmosphere through the nostrils to the lungs.

4 Your teacher will push a glass tube into the trachea and blow air hard into the tube. What happens to the lungs? Explain your observation.

5 Squeeze the trachea between your forefinger and thumb. What does it feel like?

6 Press your forefinger against the lungs. What do they feel like?

7 Observe a piece of lung tissue with a hand lens. What can you see?

Note: Wash your hands with soap after carrying out this activity.

Breathing mechanisms

Breathing is the intake of air from the atmosphere into the lungs and the release of air from the lungs into the atmosphere. The structures and mechanisms used vary from one organism to another – fish have gills; humans and other mammals, birds, reptiles and amphibians have lungs for breathing.

Breathing involves two actions – **inhalation** (breathing in) and **exhalation** (breathing out). Inhalation is brought about by the simultaneous *contraction* of the external intercostal muscles and *relaxation* of the internal intercostal muscles. These actions cause the ribs and sternum to move *upwards* and *outwards*. At the same time, the diaphragm muscles contract, flattening the diaphragm which is dome-shaped when at rest. These movements *increase* the volume of the thoracic cavity. The air pressure in the thoracic cavity falls below that of the external atmosphere. Air therefore moves under pressure from the external atmosphere into the lungs through the respiratory tubes (Figure 1.97).

In exhalation the internal intercostal muscles *contract* while the external intercostal muscles *relax*. The ribs and sternum then move *down* and *inwards* to their original positions. At the same time, the muscles of

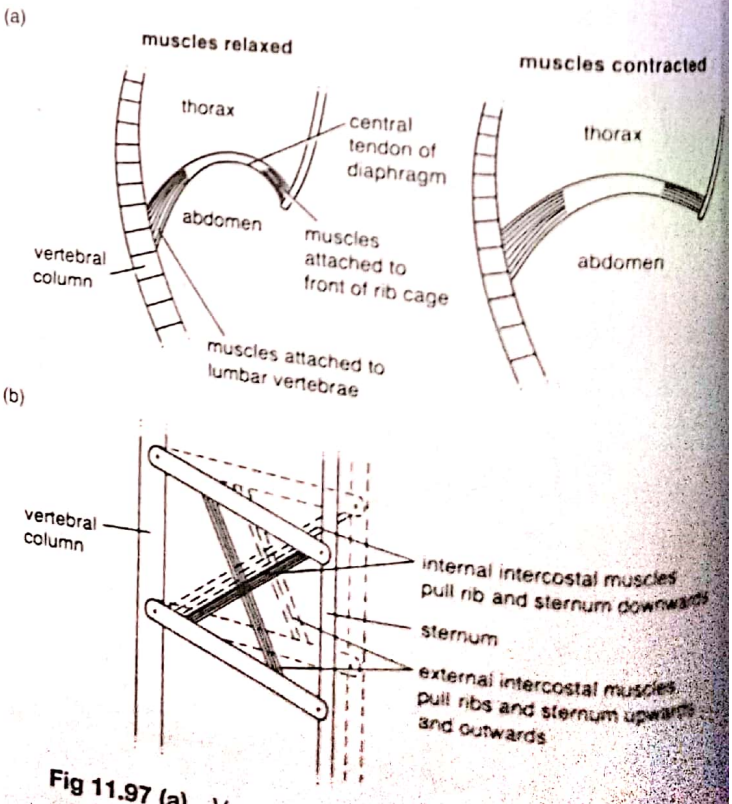


Fig 11.97 (a) Vertical section through the diaphragm showing its movements **(b)** Side view showing movement of the rib cage and sternum

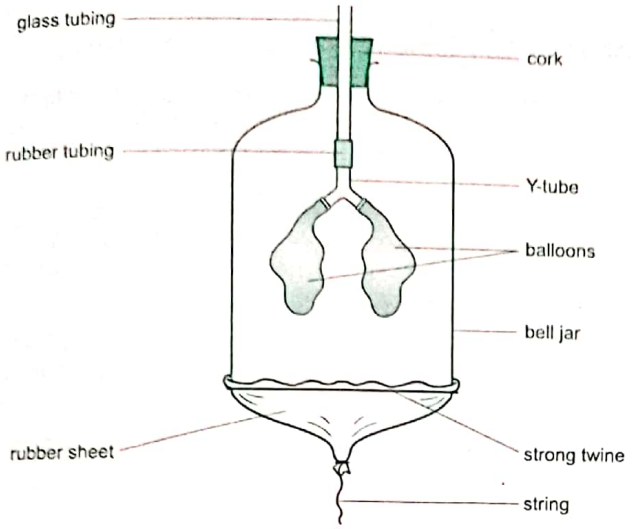


Fig 1.98 Demonstrating breathing in humans.

the diaphragm relax and the diaphragm returns to its original dome shape. The volume of the thoracic cavity then *decreases*. The air pressure in the thoracic cavity rises above that of the external pressure. Air is therefore forced out of the lungs under pressure into the external atmosphere (Figure 1.97).

ACTIVITY 6 Demonstrating breathing

1 Your teacher will set up the apparatus as in Figure 1.98. Which parts of the apparatus represent the **a)** trachea, **b)** bronchi, **c)** thorax, **d)** lungs, **e)** thoracic cavity, **f)** diaphragm?

2 Pull the rubber sheet downwards. What happens to the balloons?

3 Push the rubber sheet inwards. What happens to the balloons? What can you conclude from your observations?

Note: If new balloons are used, inflate them and allow them to deflate twice before you use them for the activity.

When the rubber sheet is pulled downwards the balloons become inflated, showing inhalation. When the rubber sheet is pushed inwards the balloons become deflated, showing exhalation.

Gas exchange in the lungs

Exchange of respiratory gases takes place in the alveoli of the lungs. Oxygen diffuses from the alveoli into the blood in the blood capillaries surrounding the alveoli. Carbon dioxide diffuses out of the blood capillaries into

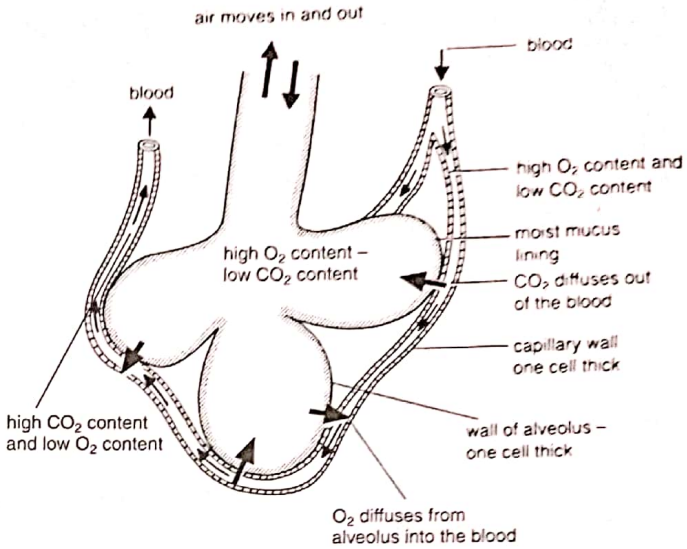


Fig 1.99 Gas exchange in the alveoli.

the alveoli (Figure 1.99). Water also evaporates from the moist lining of the alveoli so that the alveolar air becomes saturated with water vapour. The air breathed out from the lungs is therefore always moist. Inhaled and exhaled air are compared in Table 1.35.

Table 1.35 Comparison of inhaled and exhaled air

	Inhaled air	Exhaled air
carbon dioxide	0.03%	3.5%
oxygen	20.9%	16.9%
water vapour	variable	saturated
temperature	existing atmospheric temperature	body temperature (38°C)

Exhaled air contains about 17 per cent oxygen. This is why the simplest and best method of artificial respiration is to blow exhaled air into the lungs of anyone who has stopped breathing. This may have been caused by an electrical shock, inhaled gas, smoke or drowning. The method is termed mouth-to-mouth resuscitation.

The rescuer pulls the patient's head back and holds the nose closed. They cover the patient's mouth with their own mouth and blow air into the patient's mouth while feeling the chest rise as the air enters. The rescuer then removes their mouth and allows the chest to fall, or gently presses it down. They then blow in more air. This is done 18 to 20 times per minute. Many lives have been saved by the use of this simple first aid procedure.

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ACTIVITY 7 Comparison of the amount of carbon dioxide in inhaled and exhaled air

1 Set up the apparatus as shown in Figure 1.100.

2 Place your mouth over the rubber tubing and breathe in gently. Note which flask the inhaled air bubbles through. Then breathe out gently and note which flask the exhaled air bubbles through.

3 Repeat step 2 several times and record your observations.
   a) What did you observe in flask A and flask B? Explain your observations.
   b) What can you conclude from your observations?
   c) Which sample of air, inhaled or exhaled, contains more carbon dioxide?

The lime water in flask B turns milky, while the lime water in flask A remains clear.

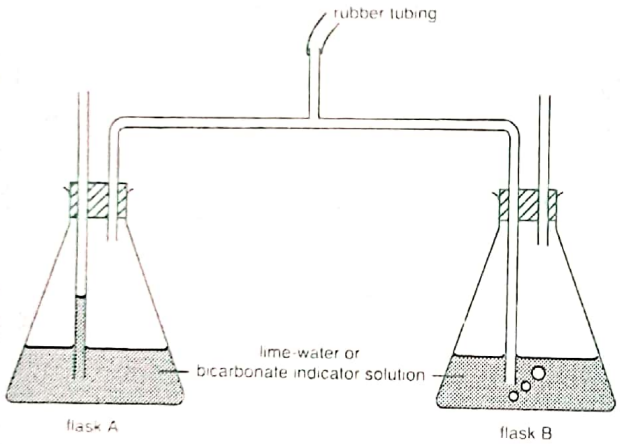


Fig 1.100 Comparison of the amount of carbon dioxide in inhaled and exhaled air.

ACTIVITY 8 Measuring your vital capacity

1 Graduate a bell jar or a large clear plastic container by pouring in several litres of water, one litre at a time, and marking the levels on the side.

2 Set up the apparatus as shown in Figure 1.101.

3 Take a deep breath and then exhale as much air as possible into the bell jar. Read the volume of water displaced in the bell jar.

4 Refill the bell jar and sterilise the mouthpiece of the glass tube with alcohol before the next pupil has a turn.

5 What is the volume of air you forced out of your lungs?

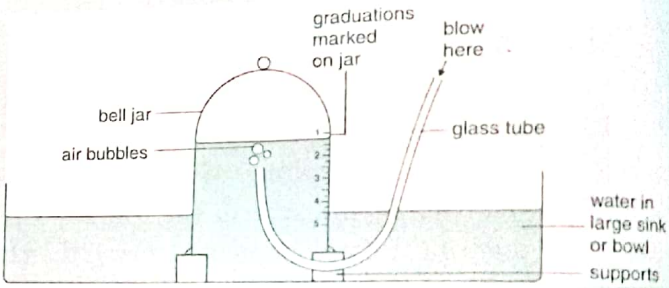


Fig 1.101 Measuring your vital capacity.

Vital capacity

The volume of air which moves in and out of the lungs at each breath is called the **tidal air**. About one-sixth of the volume of air in the lungs is exhaled with each normal breath. The air in the lungs is never completely emptied out. After breathing out as hard as you can you still have about 1.5 litres of air in your lungs. This is known as the **residual volume**. Humans and other lung-using animals can empty three-quarters of the air from their lungs during very deep breathing. This is known as the **vital capacity**. Your total lung air capacity is your vital capacity plus your residual volume.

Problems and disorders associated with the respiratory system of humans

Several problems and disorders are associated with the respiratory system of humans. Some of these are diseases caused by germs; some are due to improper functioning of certain parts of the respiratory system. They include the following:

- **Asthma** – the muscles in the walls of the bronchioles contract, making the tubes narrower. This makes breathing difficult and the person breathes with a wheezing noise. The attacks are often brought about by pollen grains, dust or a food to which the person is allergic. The attacks become worse in some people when they become nervous or worried. Drugs which make the bronchial muscles relax are used to treat asthma. The drugs make the bronchial tubes widen so that air can be breathed in and out of the lungs with ease.

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- **Pneumonia** – this is a respiratory disease caused by a bacterium called *Pneumococcus*. These bacteria cause severe inflammation of the lungs and fluid collects in the alveoli. The area over which gas exchange occurs is reduced, so the person gets short of breath.
- **Tuberculosis (TB)** – this is a deadly disease caused by a bacterium called *Mycobacterium tuberculosis*. It commonly affects the lungs but it can also affect any part of the body. The bacteria destroy the lung tissue. Tuberculosis was formerly a common cause of death but modern medicine has now made it rare.
- **Lung cancer** – the cause of lung cancer is not well known but its link with cigarette smoking and inhaling asbestos is now well established. Lung cancer results in abnormal growths in the walls of the bronchial tubes. These growths block the tubes, making breathing difficult. The cancer may spread to other organs, such as the liver and spine, unless it is detected and treated in time.
- **Whooping cough (pertussis)** – this is a serious infection of the respiratory tract caused by a bacterium called *Bordetella pertussis*. It is particularly serious in babies under three months and children with asthma. Its incubation period is only two weeks. There is severe coughing followed by 'whooping' sounds as air is inhaled through narrowed air passages.
- **Bronchitis** – this is an infection causing inflammation of the bronchi. It is common in young children and elderly people. It starts from the upper part of the bronchi and descends. The infection is caused by the common cold, influenza, measles or other conditions that cause infection of the upper part of the respiratory system. It is popularly called 'winter cough'. It is particularly troublesome in cold and foggy weather. In time it causes organic change in the lungs and heart failure may result from prolonged strain.

Exchange of respiratory gases in plants

Exchange of oxygen and carbon dioxide occurs mainly on the surfaces of the spongy mesophyll cells in the leaves of flowering plants. These gases enter and leave the internal environment of the leaves mainly through microscopic pores called **stomata** (singular: stoma) in the lower surface of the leaves.

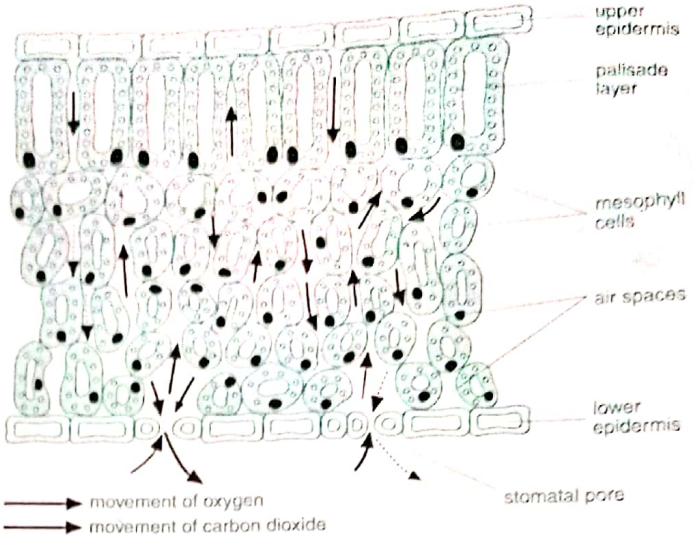


Fig 1.102 Gas exchange in a plant leaf during the night.

During the night, when photosynthesis does not occur, oxygen from the atmosphere passes through the stomata into the mesophyll layer of the leaf. The oxygen dissolves in the moisture lining the surfaces of the cells and then diffuses into the mesophyll cells where it is used in aerobic respiration. At the same time, carbon dioxide produced in these cells from respiration diffuses out of the cells and passes out through the stomata into the atmosphere (Figure 1.102).

During the day, when photosynthesis is taking place, oxygen is produced in excess of the plant's respiratory needs. This diffuses out of the mesophyll cells and passes through the stomata into the atmosphere. Carbon dioxide from the atmosphere passes through the stomata into the leaves and diffuses into the mesophyll cells where it is used for photosynthesis.

Gas exchange also occurs by diffusion through the walls of the epidermal cells of the leaves and stems. In woody plants gas exchange also takes place through pores on the stems called **lenticels** (Figure 1.103).

Gas exchange also occurs in the roots of plants. The oxygen in soil air dissolves in the thin film of water surrounding the soil particles and root hairs, and then passes into the root cells by diffusion.

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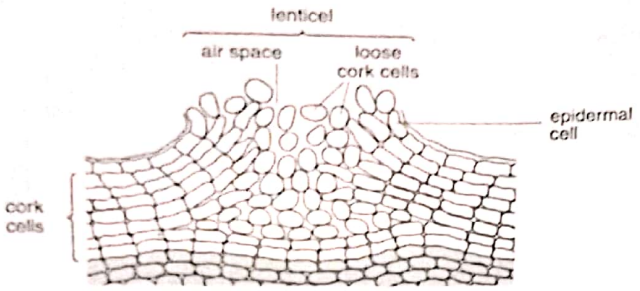


Fig 1.103 Transverse section through a lenticel.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 Which one of the following is the substrate in respiration?
A carbon dioxide **B** glucose
C oxygen **D** water

2 The correct path of air from the atmosphere to the lungs after entering the nostrils of mammals is:
A glottis → trachea → bronchi → bronchioles → lungs
B trachea → glottis → bronchi → bronchioles → lungs
C bronchi → trachea → glottis → bronchioles → lungs
D bronchioles → bronchi → trachea → glottis → lungs

3 Which one of the following is the main product of cell respiration?
A carbon dioxide **B** energy
C glucose **D** water

4 During breathing some of these processes occur:
I the ribs move upwards and outwards
II the diaphragm flattens
III the diaphragm arches upwards
IV the pressure in the thoracic cavity falls
V the pressure in the thoracic cavity rises
VI the volume of the thoracic cavity increases

Which one of the following groups of processes brings about inhalation in humans?
A I, II, III and IV
B II, III, V and VI
C I, II, IV and VI
D I, III, IV and VI

5 Which one of the following diseases of humans is caused by infection of the respiratory tract by bacteria called *Bordetella pertussis*?
A lung cancer **B** pneumonia
C tuberculosis **D** whooping cough

6 a) Define the term respiration.
b) In what ways is respiration important to living organisms?

7 a) Distinguish between aerobic and anaerobic respiration.
b) Draw and label the parts of the respiratory system of a mammal.

8 Describe the mechanisms of inhalation and exhalation in humans.

9 a) State the differences between inhaled and exhaled air.
b) List five problems associated with the respiratory system of humans.

10 a) Explain how respiratory gases are exchanged in plants.
b) Copy Figure 1.92 and indicate, using arrows, the pathways followed by oxygen and carbon dioxide in the light.

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4 Food and nutrition

Learning objectives

After studying this unit, you should be able to:

1 outline the different classes of food substances and their importance and use this information to describe a balanced diet
2 state the effects of malnutrition.

Background information

Living things take food into their bodies for healthy growth, development, and to obtain energy for life activities. This energy in food comes originally from sunlight. Organisms which contain chlorophyll (e.g. green plants) use the energy in sunlight to make food in a chemical process known as photosynthesis. These organisms are described as **autotrophic** (self-feeders) because they make and use their own food. They are also described as **holophytic** because they use light energy for the synthesis of food.

Photosynthesis is the process by which green plants manufacture carbohydrates from carbon dioxide and water in the presence of sunlight and give off oxygen as a by-product. This is summarised in the chemical equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Photosynthesis is important because it creates the sugars that make life possible. It produces chemical energy as well as the building blocks needed to make cells.

Photosynthesis is the process that underlies virtually all life on Earth.

Types of food substances

The different classes of food substances are:

- carbohydrates
- proteins
- fats and oils (lipids)
- vitamins
- mineral elements
- water
- roughage (dietary fibre).

Carbohydrates

These are compounds which contain the elements carbon, hydrogen and oxygen. The ratio of hydrogen to oxygen is 2:1 as in water (H_2O). They have the general formula $C_x(H_2O)_y$, where x and y are whole numbers.

There are three types of carbohydrates: **monosaccharides**, **disaccharides** and **polysaccharides**.

Monosaccharides

These are commonly known as simple sugars. Because they have a reduction action on Benedict's solution and Fehling's solutions, they are more appropriately called **reducing sugars**. Their general formula is $C_6H_{12}O_6$. The molecular structure of a monosaccharide is shown in Figure 1.104.

Monosaccharides are white crystalline solids, have a sweet taste and are soluble in water. Examples include galactose in milk, glucose in fruits, fructose in flower nectar, fruits and honey.

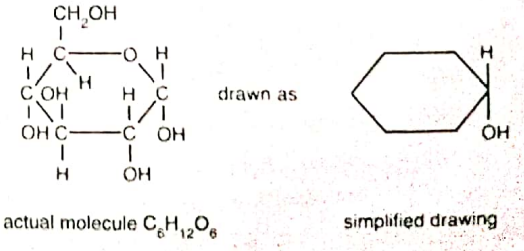


Fig 1.104 Molecular structure of a monosaccharide, e.g. glucose.

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ACTIVITY 1 Test for reducing (simple) sugars, e.g. glucose

1 Place 2 cm^3 of glucose solution in a test tube. Place 2 cm^3 of distilled water in another test tube as a control.

2 Add 2 cm^3 of Benedict's solution or Fehling's solutions A and B to each test tube. (Fehling's solutions A and B should first be mixed in a 1:1 ratio.)

3 Heat the test tubes for 5 minutes in a boiling water bath and allow to cool. A colour change from clear blue to opaque green, yellow and finally to orange or brick-red precipitate indicates the presence of a reducing sugar (Figure 1.105).

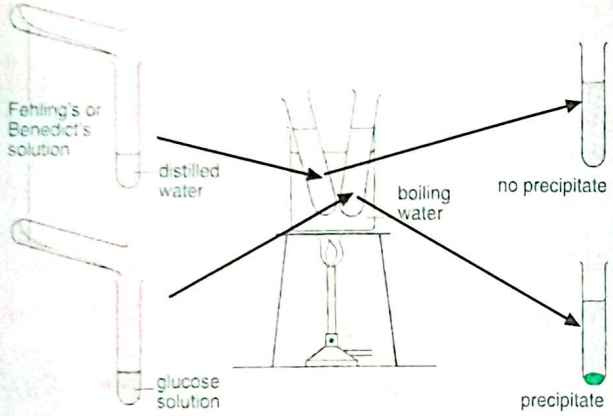


Fig 1.105 Testing for reducing sugars.

4 What change(s) do you see in each test tube?

5 Explain your observations.

6 What do you learn from this experiment?

In medical laboratories the test for sugar in the urine of diabetics is based on this test.

Disaccharides

These are commonly known as complex sugars. A disaccharide sugar contains two monosaccharide units linked together by a chemical bond in a chemical process known as condensation, in which one water molecule is lost. Their general formula is $C_{12}H_{22}O_{11}$. The molecular structure of a disaccharide is shown in Figure 1.106.

Like monosaccharides, disaccharides are white crystalline solids, sweet and water soluble. Some examples of disaccharides are sucrose (table sugar), found in sugar cane and sugar beet, and lactose (milk sugar) and maltose, found in germinating grains, e.g. maize and barley. All disaccharides except sucrose are also reducing

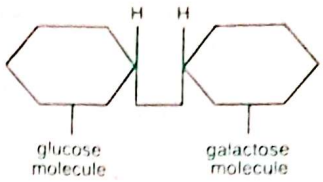


Fig 1.106 Molecular structure of a disaccharide, e.g. lactose.

sugars. Sucrose is called a **non-reducing sugar** because it has no reduction action on Benedict's solution and Fehling's solutions.

Disaccharides can be broken down into monosaccharides in a chemical process known as **hydrolysis**. The hydrolysis can take place in the presence of dilute acids, such as dilute hydrochloric acid, or biological catalysts called enzymes. Hydrolysis of complex sugars is the reverse of their condensation process.

ACTIVITY 2 Test for non-reducing sugars, e.g. sucrose

1 Repeat the Benedict's or Fehling's test with sucrose solution.

2 Record your observations.

3 Place another 2 cm^3 of sucrose solution in a test tube, add six drops of dilute hydrochloric acid and heat for 2–3 minutes in a boiling water bath.

4 What is the purpose of adding dilute hydrochloric acid?

5 Cool the mixture under cold tap water or in a beaker of cold water and add solid sodium hydrogen carbonate ($NaHCO_3$) a little at a time until the fizzing stops. This neutralises the acid which may interfere with the action of Benedict's solution or Fehling's solutions.

6 Explain the cause of the fizzing.

7 Add 2 cm^3 of Benedict's solution or Fehling's solutions A and B to the mixture and boil in a water bath for 5 minutes.

8 Record and explain your results.

Polysaccharides

These consist of several monosaccharide sugars joined together by chemical bonds. Their general formula is $(C_6H_{10}O_5)_n$, where 'n' is a large number, about 300 for starch and 300 to 3000 for cellulose. The molecular structure of a polysaccharide is shown in Figure 1.107.

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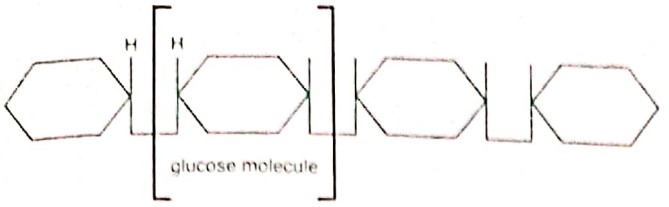


Fig 1.107 Molecular structure of a polysaccharide, e.g. starch.

Polysaccharides are not sweet and usually insoluble in water. Examples include starch, cellulose, glycogen, chitin (formed from many glucose units) and inulin (formed from many fructose units).

Chitin is a polysaccharide that includes amino acids as well as glucose units.

ACTIVITY 3 Test for starch

1 Put a few drops of starch solution on a white tile.

2 Add a few drops of iodine solution. Record the colour change. A blue-black colour indicates starch.

Uses of carbohydrates

Carbohydrates have many uses in living things, including:

- an immediate source of energy, e.g. glucose
- as food storage compounds, e.g. starch in plants, glycogen in animals
- as structural components, e.g. cellulose in plant cell walls, chitin in exoskeletons of arthropods and in the cell walls of fungi.

Proteins

These are compounds which always contain the elements carbon, hydrogen, oxygen and nitrogen. Some proteins contain sulphur and phosphorus also. The smallest unit of protein is called an **amino acid** and 20 of these occur naturally in living things. One protein molecule contains from several hundreds to thousands of amino acids chemically linked together by peptide bonds or peptide linkage (Figure 1.108).

Proteins may be described as **first class proteins** or **second class proteins**. First class proteins are found in animals. They contain all the essential amino acids necessary for healthy growth and development. Second class proteins are plant proteins and are lacking in some

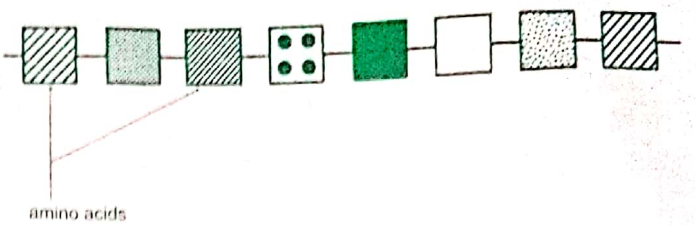


Fig 1.108 Many amino acids join together to form a protein.

of the essential amino acids needed for healthy growth and development of animals.

Proteins are **denatured** (destroyed) by temperatures higher than 60°C, solutions of strong acids and alkalis, and organic solvents. A denatured protein loses its chemical structure and physical texture, e.g. a boiled egg.

Uses of proteins

Proteins are important to all living things because they are used for the formation of several organic substances:

- muscles, cartilage and tendons
- protoplasm, leading to growth, repair and replacement of dead cells and tissues
- hormones
- enzymes
- keratin – the main constituent of hair, nails, horns and hooves of some animals.

Proteins are occasionally respired to provide energy, especially in carnivores. Humans may also respire proteins for energy when carbohydrates, fat and oil sources are depleted. Sources of proteins include meat, beans, eggs and fish.

ACTIVITY 4 Test for proteins

1 Place 2 cm^3 of egg albumen, mashed meat or cowpea in a test tube and add 1 cm^3 of dilute sodium hydroxide (NaOH) solution.

2 Carefully add 1 per cent solution of copper sulphate ($CuSO_4$) drop by drop, shaking the test tube after each drop.

3 What colour change do you notice? A purple (violet) colour indicates the presence of proteins (Figure 1.109).

4 What do you learn from the results?

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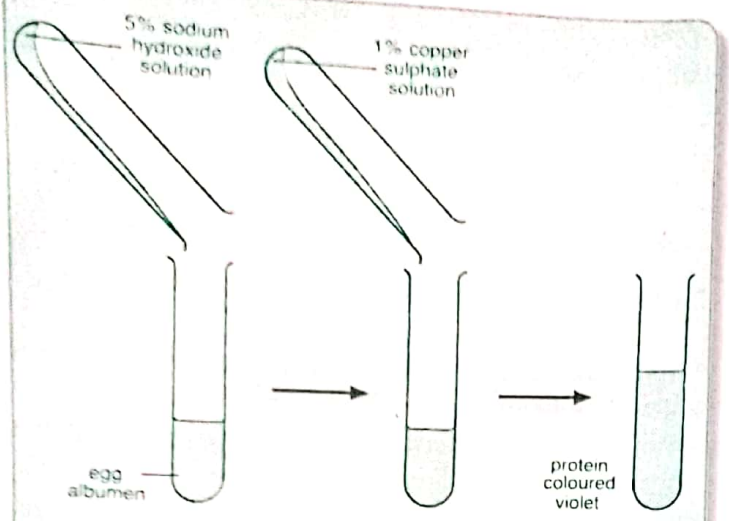


Fig 1.109 Testing for proteins.

Lipids

These are compounds containing the elements carbon, hydrogen and oxygen, but the ratio of hydrogen to oxygen is not 2:1 as in carbohydrates. The amount of oxygen atoms in the structure of lipids is far lower than that in carbohydrates. Lipids include fats and oils. Their structure is formed from glycerol and fatty acids combining chemically (Figure 1.110). Animals store fats while plants store oils.

Fats are solid at room temperature, while oils are liquid. Lipids, when rubbed on a white sheet of paper, form a translucent patch on the paper. Fats and oils are soluble in organic solvents, e.g. ethanol, but insoluble in water, an inorganic solvent. Thus fats and oils form an **emulsion** of small droplets dispersed and suspended in the water.

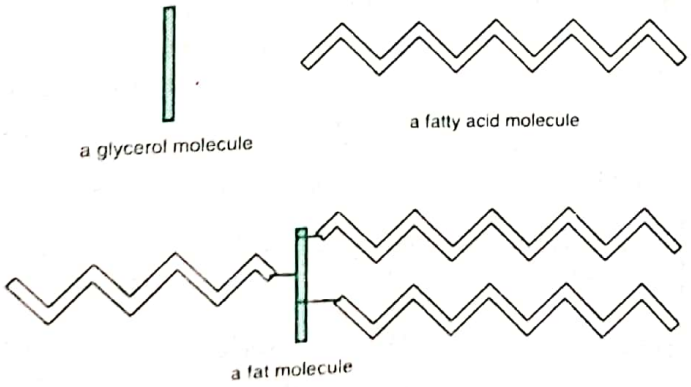


Fig 1.110 How glycerol and fatty acids join to form a fat.

ACTIVITY 5 Grease spot test for lipids

1 Rub a piece of margarine or shea butter on a white sheet of paper or make an oily spot.
2 Make a spot of water with a clean finger tip beside the spot of lipid.
3 Leave the paper for 10 minutes, then hold it in front of your eyes and observe carefully.
4 Record and explain your observations. (A translucent patch shows the presence of lipids.)

ACTIVITY 6 Emulsion test for lipids

1 Place 2 cm^3 of ethanol in a test tube and add 2 cm^3 of oil, e.g. palm oil or groundnut oil.
2 Place your thumb over the mouth of the test tube, shake vigorously and pour the mixture into another test tube containing 2 cm^3 of water.
3 Record and explain your observation. (A cloudy, white emulsion shows the presence of lipids.)

Uses of lipids

Lipids have many uses in living organisms, including:

- storage in adipose (fatty) tissue under the skin of mammals – the fat serves as food reserve and heat insulator
- as a fatty sheath around nerve fibres to prevent loss of electrical impulses and to speed nerve transmission
- a source of energy when respired – weight for weight, lipids release twice as much energy as carbohydrates and proteins
- used in aquatic animals to enhance buoyancy (floating); large quantities of stored fats and oils decrease the density of the body
- used as structural materials, taking part in the formation of cell membranes
- used in dissolving fat-soluble vitamins
- used as waterproofing in the form of waxes, e.g. the cuticle of leaves or the exoskeleton of arthropods
- some hormones are produced from lipids.

Sources of fats include fatty meat, butter and margarine; sources of oils include coconut oil, palm oil and groundnut oil.

Vitamins

These are organic food substances required by the human body in very minute quantities for normal

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Table 1.36 Vitamins: their sources, functions and symptoms of deficiency

Vitamin	Source from normal food	Special source	Symptom of deficiency	Special notes
A retinol	liver, egg yolk, green vegetables, red palm oil, cocoa, carrots	butter, margarine, cod-liver oil	sore eyes, reduced night vision, colds and bronchitis, unhealthy skin	carotene from plant pigment converted to vitamin A in intestine walls
B_1 thiamine	unpolished cereals, palm wine, beans, lean meat, egg yolk	bread, milk, kidney	retarded growth, lack of appetite in children, nerve inflammation, weakness, paralysis, the disease called beri-beri	likely in rice-eating peoples
B_2 riboflavin	as for B_1, plus green vegetables	as for B_1, plus liver and Marmite	skin disorders, eye and mouth membrane sores, the disease called dermatitis	
nicotinic acid	as for B_1, plus yams and green vegetables	as for B_1	digestive disorders, mental disorders, the skin disease called pellagra	likely in maize-eating peoples
C ascorbic acid	fresh fruit, citrus fruit (e.g. oranges, lemons, grapefruit), raw vegetables	prepared concentrated fruit juices	bleeding from gums and other membranes, teeth disorders, reduced resistance to infection, the disease called scurvy	common fatal disease on old sailing ships where sailors had no fresh fruit
D calciferol	liver, fat, fish, egg yolk, formed in the skin by sunlight	butter, margarine	weak bones, particularly leg bones, weak teeth, the disease called rickets (Figure 1.111)	young mammals susceptible to disease; unlikely in the tropics where there is plenty of sunshine
K	liver, green vegetables, egg yolk, unpolished cereals		prolonged bleeding (essential for blood clotting)	made by bacteria in the gut

growth and development (Table 1.36). They also keep the body healthy and prevent the occurrence of certain deficiency diseases. The well-known vitamins are A, B, C, D, E and K, named in order of their discovery. Their chemical natures were later determined and chemical names were given to them. Some vitamins have subdivisions because of different chemical structures, e.g. vitamin B_1, B_2 and B_{12}.

Minerals

These are inorganic food substances. They are obtained from organic foods by humans in the form of salts and ions. Although needed by the body in very small amounts, they are essential for the normal functioning of the body. Lack of certain mineral elements in the human body results in deficiency diseases (Table 1.37).

Water

Water is essential for all living organisms. It is obtained by humans from food and by drinking it. In the body water is involved in the following processes:

- all chemical reactions
- transportation of substances, e.g. food, oxygen, hormones, wastes
- even distribution of heat



Fig 1.111 A child suffering from rickets.

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Table 1.37 Mineral elements: their sources, functions and symptoms of deficiency

Element	Source in food	Importance to the mammalian body
nitrogen N	protein foods – lean meat, fish, eggs, milk	for synthesis of protein and other complex chemicals, formation of muscle, hair, skin and nails
sulphur S	as for nitrogen	as for nitrogen
phosphorus P	as for nitrogen	for synthesis of protein and other complex chemicals, formation of ATP; absence causes rickets (Figure 1.111)
iron Fe	liver, green vegetables, yeast, eggs, kidney	forms haemoglobin in red blood cells; absence causes anaemia
calcium Ca	milk, cheese, green vegetables	formation of bones and teeth, necessary for muscle contraction and blood clotting; absence causes rickets (Figure 1.111)
iodine I	sea fish and other sea foods, cheese, iodised table salt	formation of thyroxin (hormone in the thyroid gland); absence causes goitre and reduced growth (Figure 1.112)
sodium Na	table salt, green vegetables	maintenance of tissue fluids, blood and lymph; transmission of nerve impulses
potassium K	vegetables	transmission of nerve impulses
chlorine Cl	table salt	maintenance of tissue fluids, blood and lymph



Fig 1.112 Child suffering from goitre due to a lack of iodine in the diet.

- cooling the body (when it evaporates from the body surface)
- dissolving substances.

Roughage (dietary fibre)

This is not actually a food substance, but because of its importance in the diet, it must always be mentioned when dealing with food substances. It is indigestible fibrous material made up mostly of cellulose. Some gut bacteria in humans digest the cellulose and produce important vitamins which the body absorbs and uses. It gives bulk to the diet, and by stimulating the gut muscles to contract properly, moves food smoothly through the gut. It therefore facilitates free bowel movement and prevents constipation, reducing the risk of bowel cancer. This explains why it is important to include roughage in the diet. Sources of roughage are the solid fibre parts of fruits, such as oranges, pineapples and apples. Vegetables and cereals are also good sources of fibre.

ACTIVITY 7 Testing different foods

1 Collect various types of food, e.g. ripe citrus fruits, ripe and unripe bananas or plantain, a tuber of cassava or yam, maize grains, cowpeas, groundnut seeds, castor oil seeds, sugar cane, ripe and unripe pawpaws, ripe and unripe mango fruits, potato and ripe palm nuts.
2 Crush and prepare a solution or suspension from each type of food and carry out the tests for sugars, starch, fats and proteins described above to find out the food substance in each type of food.
3 Construct a table to record your results.

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Balanced and unbalanced diets

Diet is the variety of food and drink which a person takes into the body. A **balanced diet** is one that includes all the classes of food substances in their correct proportions and quantities needed by the body to function properly. On the other hand, a diet that includes too little or too much of one or a number of food substances is described as an **unbalanced diet**. Table 1.38 shows the proportions of different foods in a balanced diet, while Table 1.39 shows a week's menu of a balanced diet from a secondary boarding school in Ghana.

These proportions vary with the age, sex, occupation, condition and environment of different categories of people. For example, a pregnant woman must take high amounts of calcium in her diet to help build strong bones for the foetus.

Table 1.38 Percentages of foods in a balanced diet

Food class	Percentage	Function
carbohydrates	55%	produce energy
fats/oils	15%	energy store
proteins	20%	body building
water, vitamins and minerals	10%	protective and body building

Effects of malnutrition

Eating an unbalanced diet has adverse effects on the health of people of all ages. This is known as **malnutrition**. Inadequate amounts of certain food substances in the diet leads to various diseases known as **deficiency diseases**.

- Inadequate amounts of protein in the diet of children after weaning causes a deficiency disease known as **kwashiorkor** (Figure 1.113). The stomach becomes distended (enlarged) due to retention of too much fluid. Such children have thin legs and arms, skin discolouration, diarrhoea and anaemia. Their skin also cracks and becomes scaly. Their liver fails to function properly and the child may die. Kwashiorkor can be cured at its early stage with a special high-protein diet, e.g. a mixture of skim-milk powder and vegetable protein or mashed bean with finely pounded 'keta school boys'. If kwashiorkor is prolonged, the child may be mentally and physically retarded.

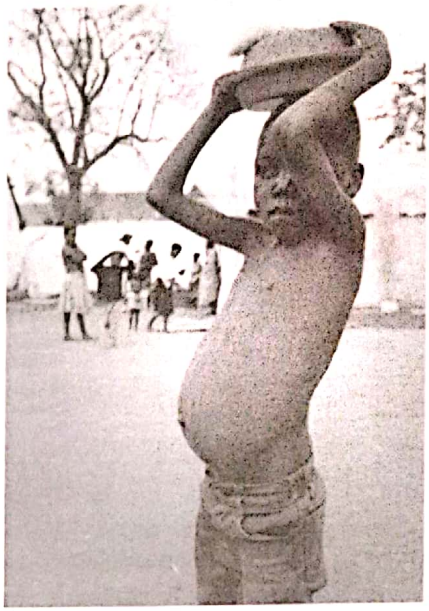


Fig 1.113 A child suffering from kwashiorkor.

- **Night blindness**, a condition in which people have reduced night vision, is caused by lack of vitamin A in the diet (see Table 1.36).
- Deficiency of **iodine** in the diet causes **goitre** in humans. It is seen in people as an enlarged neck as a result of enlargement of the thyroid gland (Figure 1.112 and Table 1.37). Sea foods are good sources of iodine. Goitre can be prevented or stopped at an early stage by including iodised salt in the diet.
- Deficiency of **calcium** in the diet causes a disease in children known as **rickets**. The disease results in poor formation of bones leading to deformities (see Figure 1.111 and Table 1.37).
- **Lactose intolerance** is the inability to metabolise lactose, a sugar found in milk and other dairy products, because the required enzyme lactase is absent or its availability is lowered. Symptoms include stomach cramps, bloating and flatulence. The condition can be managed by avoiding lactose-containing products or use of lactase supplements.

Over-nutrition

A diet which contains more food than the body needs for its energy demand can cause problems, especially in middle age and old age. For example, people who eat large quantities of animal fat risk high levels of cholesterol in their blood. Cholesterol is a fatty substance found in animal fats, and also in coconut oil and palm oil. Cholesterol is deposited in the walls

Table 1.39 A week's menu of a balanced diet for a secondary boarding school in Ghana

	Breakfast	Lunch	Supper
Monday	rice water, bread and groundnut	akple with fresh fish soup; orange or pineapple	kenkey with hot pepper and fried fish
Tuesday	koko, bread and groundnut	boiled yam with nkontomire stew	rice with fish stew
Wednesday	Tom brown with bread and boiled egg	banku with garden egg stew; orange	boiled yam with meat stew; orange or pineapple
Thursday	tea/coffee with milk, bread and margarine	rice and beans (wakye) with fish stew	banku with fried fish and hot pepper
Friday	ekuegbe with bread and fried egg	yakayake with palm nut soup; orange	akple with groundnut soup; orange or pineapple
Saturday	beans and gari; banana	rice and beans with meat stew	rice with nkontomire stew
Sunday	oblayo bread and ground nut	beans and fried plantain (red-red); orange or pineapple	kenkey and fried fish with hot pepper; orange or pineapple

of the arteries, hardening them and making then narrower. The flow of blood through the arteries is restricted, making the heart pump harder and raising the blood pressure. This results in a condition known as **hypertension** or **high blood pressure**. More strain is put on the heart, which overworks itself to sustain the flow of blood. This may lead to **heart failure** (heart attack) when the heart suddenly stops functioning. The high blood pressure also pushes out the walls of the arteries and may burst them. If this happens in the brain, the spillage of blood into the brain tissue (brain haemorrhage) kills the brain cells around the damaged artery. This results in a condition called a **stroke**. The person is partially paralysed and cannot speak properly. A severe stroke can cause death.

A person who eats more food than the body requires also becomes **obese** (overweight) because the excess food is converted into fats and stored under the skin. Eating too much refined sugar (table sugar or white sugar) may lead to obesity, which contributes to high blood pressure and heart disease. It may also cause tooth decay. Eating a lot of sugar may also be a factor in the development of **diabetes mellitus**.

Appendix VI gives the common sources of the different classes of food. You can use this together with Table 1.38 to check your diet to find out if you are eating the correct amounts of each class of food material.

ACTIVITY 8 Effects of malnutrition

Work in groups to discuss the effects of malnutrition and why roughage is important in the diet.

Self check

For questions 1 and 2, choose the letter that refers to the correct option.

1 A balanced diet contains:
- **A** all the energy giving foods
- **B** all the food substances
- **C** all the food substances in their correct proportions
- **D** all the food substances in their correct proportions and quantities

2 Which of the following diseases is caused by vitamin deficiency?
- **A** ascariasis
- **B** dysentery
- **C** night blindness
- **D** tuberculosis

3 Name the different classes of food substances and describe two uses for each.

4 a) Name the process by which disaccharides are formed.
b) Describe a test for reducing sugars.

5 a) Distinguish between first class and second class proteins.
b) Describe a test for proteins.

6 a) Distinguish between a balanced diet and an unbalanced diet.
b) Define malnutrition.

7 a) What are the features of a child suffering from kwashiorkor?
b) How can kwashiorkor be cured?

8 What disease is likely to occur in a child whose diet lacks:
- a) proteins?
- b) iodine?
- c) calcium?

9 Briefly describe and explain the causes of hypertension.

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5 Dentition, feeding and digestion in mammals

Learning objectives

After studying this unit, you should be able to:

1 identify the different types of teeth in mammals and relate them to their functions
2 enumerate various ways of preventing dental problems
3 draw and label the digestive system of mammals
4 describe the process of digestion, absorption and assimilation in mammals
5 mention some diseases and disorders associated with the digestive system of humans.

Background information

Animals, including humans and other mammals, depend on complex food substances for nutrition.

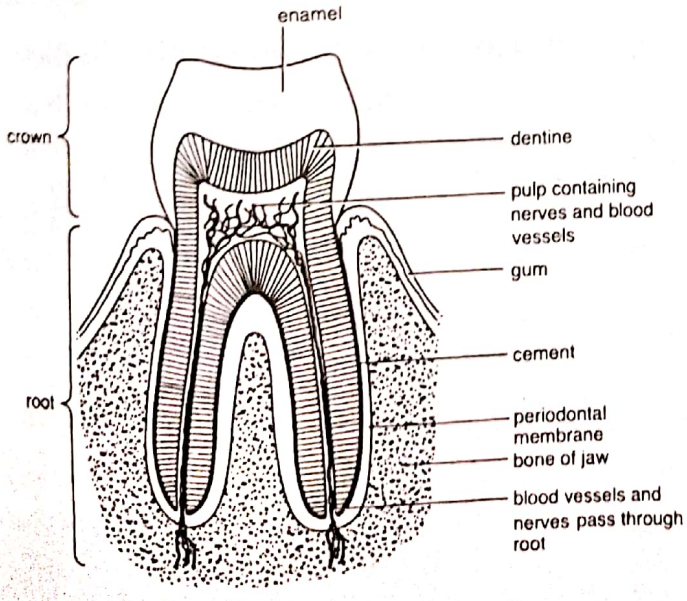


Fig 1.114 Vertical section through a human premolar tooth.

These complex food substances cannot be used by animals unless they are broken down into simpler substances. The digestive system converts the complex food substances taken in by animals to simple forms which the body can use.

Our teeth play an important role in the process by first breaking down large pieces of solid food into smaller pieces for enzymes to act on. It is therefore necessary to take good care of our teeth to keep them healthy.

The liver is a vital organ associated with the digestive system. It performs useful functions in digestion and assimilation. It is biochemically indispensible.

Structure, functions and types of teeth in mammals

Tooth structure

Teeth develop from a group of cells in the skin overlying the jaw bones. Humans and other mammals have different kinds of teeth. Although teeth differ in shape and size and perform different functions, their internal structure is similar (Figure 1.114).

Each tooth has a **crown** which projects above the gum and a **root** which is buried in a socket in the jaw bone. The crown is covered with **enamel**, a layer of very hard, shiny material composed mainly of calcium phosphate. Beneath the enamel and extending into the root is the **dentine**, which makes up the greatest bulk of the tooth. Dentine is a type of hard bone, but is not as hard as the enamel. Fine channels, containing living material, pass through the dentine. The dentine encloses a central **pulp cavity**. Pulp consists of blood vessels, tooth-forming cells and nerve fibres with sensory nerve

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endings which penetrate the dentine, making it very sensitive to pain and temperature changes.

Teeth are fixed in the jaw bone by **cement**, a hard, bony substance that covers the outside of the root. Attached to the cement are tough **periodontal fibres** which run into the jaw bone. These fibres hold the tooth in its socket and permit slight tooth movements that cushion the tooth from excessive jarring when it hits a hard object. Some teeth have a single root while others have two or three roots.

ACTIVITY 1 Examining the tooth structure of mammals

1 Your teacher will provide you with a model of a human tooth showing its external and internal structures.

2 Carefully examine the model and, using Figure 1.114 as a guide, draw and label the parts of the tooth.

Types of teeth and their functions in humans

Humans have four different types of teeth – incisors, canines, premolars and molars. These are shown in Figure 1.115.

- **Incisors** – two pairs of chisel-shaped teeth in the front part of each jaw in humans. Each has a broad, flat cutting edge for biting and cutting solid food when the lower and upper incisors pass each other. Incisors have a single root.
- **Canines** – next to the incisors, one in each half of each jaw. They are conical, bluntly pointed and just slightly longer than the incisors. They perform similar functions to the incisors in humans, i.e. biting and cutting solid food. Canines have a single root.

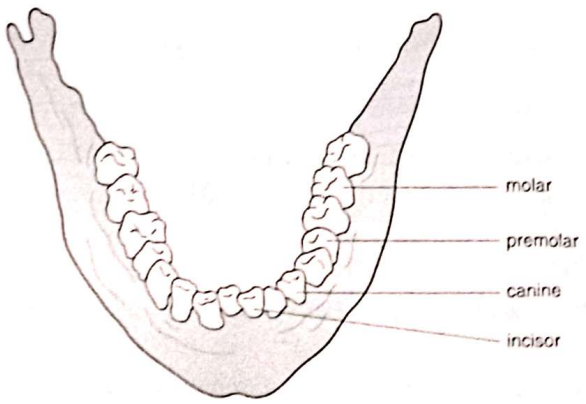


Fig 1.115 Types of teeth in an adult human.

- **Premolars and molars** – collectively called cheek teeth. There are two premolars in each half of each jaw. They have flat tops with two small cusps (pointed ridges). The last three teeth on each half of each jaw are the molars. They also have flat tops like the premolars but have four or five cusps. During chewing the upper and lower premolars and molars meet. The cusps of one set fit into the depressions of the other set, crushing and grinding solid food. Premolars have one or two roots. The upper molars have three roots while the lower molars have two roots.

Humans and other mammals have a succession of two sets of teeth in their lifetime. The first set of 20 teeth, called **milk teeth**, are found in young humans. They include incisors, canines and premolars but no molars. These small teeth fall out one by one in early life and are replaced by the permanent teeth. The last molar teeth in each jaw are called wisdom teeth because they are the last to appear when the person is between 17 and 25 years old.

ACTIVITY 2 Examining the different types of teeth in humans

1 Your teacher will provide you with a model of a set of human teeth.

2 Carefully study the model and, using Figure 1.115 as a guide, draw and label the different types of teeth.

3 Write down the functions of each type of tooth.

Types of dentition and their relation to diet

The characteristics of the teeth make up the dentition. In mammals, for example, the teeth vary in size, shape and function – this is known as **heterodont** dentition. Vertebrates, such as fish, amphibians and reptiles, have teeth of the same size, shape and function – their dentition is described as **homodont**.

Dental formula

This is a summary of the number, types and arrangement of teeth in one half of the lower and upper jaws of a mammal. The 32 teeth in adult humans, for example, can be summarised as i 2/2, c 1/1, pm 2/2, m 3/3, where the initials are incisors (i), canines (c) premolars (pm) and molars (m), respectively. The figures on the lines

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represent the teeth in the upper jaw and those below the lines are the teeth in the lower jaw. The total number of teeth of an adult human can therefore be obtained by multiplying the sum of the figures indicated in the dental formula by 2, i.e. 2 (4 + 2 + 4 + 6) = 32.

Relation of dentition to diet

Humans are **omnivores**, i.e they feed on both animal and plant materials. Their teeth are therefore not highly specialised. Humans can move their lower jaw up and down, side to side and backwards and forwards.

Carnivorous (flesh-eating) mammals, e.g. dog, cat, lion, have highly specialised teeth. The dental formula of a dog is 2 (i 3/3, c 1/1, pm 4/4, m 2/3) = 42 (Figure 1.116).

The incisors are small, peg-like and chisel-shaped, and are used for seizing prey. The canines are long, conical, pointed and curve slightly inwards. They are used to hold and kill the prey, and tear flesh. All the premolars and molars are relatively small except for the first lower molars and the last upper premolars which are greatly enlarged. These are called the **carnassial teeth**. They have smooth sides and sharp cusps and edges that run along the jaw line. They slide past each other like the blades of a pair of scissors and are used for scraping flesh off bones. The remaining molars have blunt cusps for crushing bones. The muscles at the joint between the lower jaw and skull are so arranged that only up and down movements of the lower jaw are possible.

Some **herbivorous** (plant-eating) mammals, e.g. rabbits, grass-cutters and mice, have long, chisel-shaped incisors for cutting and gnawing vegetation. They also have a row of file-like premolars and molars with flat, ridged surfaces for grinding plant material. They lack canines but instead have a large gap called a **diastema** between the incisors and premolars. The dental formula of the rabbit is 2 (i 2/1, c 0/0, pm 3/2, m 3/3) = 28.

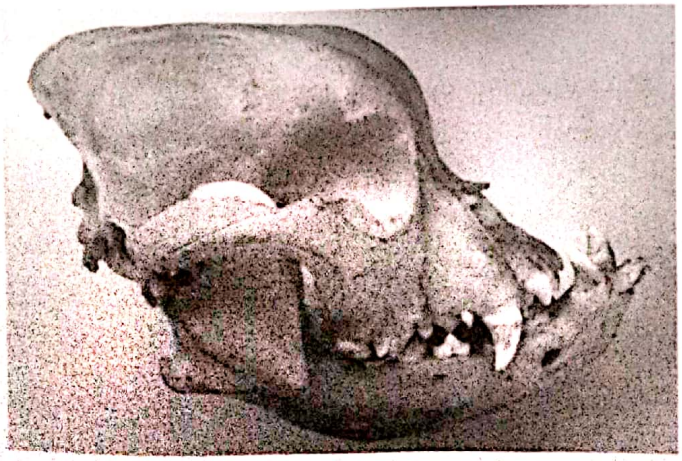


Fig 1.116 The jaws and teeth of a dog.

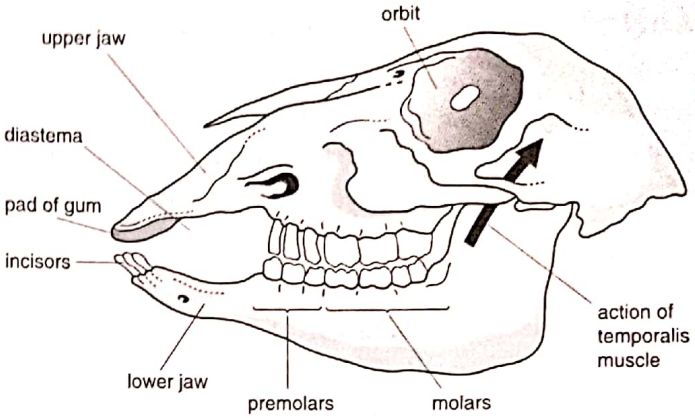


Fig 1.117 The jaws and teeth of sheep.

The incisors of some rodents have open roots, i.e. they continue growing throughout the animal's life. Thus a continuous biting surface is always present, even though the teeth are worn down by the tough cellulose in plant material. The muscles between the lower jaw and skull are so arranged that they allow up and down movements of the lower jaw for cutting and grinding vegetation, and backward and forward movements for gnawing.

Ruminant herbivores such as sheep and cows have the dental formula 2 (i 0/3, c 0/1, pm 3/3, m 3/3) = 32 (Figure 1.117). As their dental formula shows, they lack upper incisors and canines. Instead there is a hard pad against which the lower incisors and canines bite to tear off grass. The crowns of the premolars and molars are broad and flattened, and have transverse ridges used for grinding vegetable material. The muscles between the lower jaw and skull allow side to side movements of the lower jaw during chewing.

ACTIVITY 3 Examining the jaws and teeth of other mammals

1. Your teacher will provide you with skulls of a rabbit and a sheep.
2. Carefully examine the jaws and teeth. Make a labelled drawing of them using Figure 1.117 as a guide.
3. *Work in groups* to discuss the functions of the various structures.

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Care of the teeth in humans

In order to prevent and control dental problems, it is important for us to take good care of our teeth. If we don't, we risk suffering from **dental caries** (tooth decay) and **periodontal disease** (infection of the gums and tooth sockets).

Tooth decay

This is caused by a lack of hard food, eating too much sugary food such as cakes, biscuits, sweets and ice cream, drinking sweet drinks such as cola, lack of calcium in the diet, lack of vitamin D, lack of cleaning and general ill health. It is the result of erosion of the enamel and dentine. Bacteria feed on sugar and starch in the mouth cavity. Their enzymes act on the sugar and starch and produce acids, particularly lactic acid, as a by-product. The acid reacts with calcium in the enamel and dentine, starting from the crevices between the cusps on the surface of the crown and between the teeth. The acid breaks down the enamel and dentine, creating a hole in the tooth which eventually perforates the pulp cavity. Bacteria then invade and infect the pulp, including the sensitive nerve endings, causing toothache. The infection may spread to the base of the tooth, causing an abscess which is very painful.

If the decay has not gone into the pulp cavity, the tooth can be repaired by a dentist. This is done by carefully cutting away the decayed parts of the tooth with a drill, and filling the hole with a substance which hardens quickly. Cheek teeth are filled with a mixture of silver and tin, while the front teeth are filled with porcelain or a plastic which has the same colour as the teeth. If the decay has gone into the pulp cavity the tooth may have to be removed or crowned, because at that stage the dentist cannot repair the tooth.

Periodontal disease

This is encouraged by a lack of vitamins A and C, lack of massage of the gum and imperfect cleaning of the teeth. There is always a thin film of saliva on the surface of the teeth. If not regularly removed by cleaning, food debris and bacteria accumulate in the film to form a permanent hard, thin coating on the surface of the teeth called **plaque**. The plaque may become mineralised, forming a harder plaque called **tartar**. This cannot be removed by ordinary cleaning of teeth.

It can only be removed by a dentist by a method known as scaling.

Periodontal disease (gum disease) occurs when the bacterial plaque spreads down the tooth into the crevices at the junction of the tooth and gum. Inflammation of the gum occurs, leading to bleeding, bad breath and gum recession. As the gum continues to recede, the cement is exposed and the fibres holding the tooth in its socket break down. The tooth becomes loose and falls out. More teeth are lost through periodontal disease than through dental caries.

Pyorrhoea

This is another common dental disease characterised by reddening and bleeding of the gums, and presence of pus. The fibres which hold the tooth in its socket are infected. The tooth then becomes loose and falls out.

Care of the teeth

Dental care must aim at always keeping the teeth in a healthy condition. This can be achieved by proper use of the teeth, keeping the teeth clean and receiving regular expert attention. The following methods are recommended by dentists.

Proper use of the teeth

Teeth are meant for eating food. They should therefore not be put to improper uses, such as opening bottle tops and cracking nuts and very hard bones. The teeth must, however, be given exercise by chewing hard food. Children should be given a bone ring or other hard object from time to time to chew. People should also finish their meal with tough, fibrous vegetables, such as raw carrots, cashews, apples, pineapples, oranges and other fruits, and rinse their mouth with water after the meal.

Keeping the teeth clean

Teeth must be cleaned regularly to remove food debris on which bacteria feed and produce the acids that cause tooth decay. Use a tooth pick to remove food from the spaces between the teeth. Teeth should be brushed regularly with a toothbrush and toothpaste, chewing stick and sponge, after each meal, before going to bed at night and first thing in the morning. Using a small piece of clean rag and some table salt to clean the teeth is also effective if a toothbrush is not available. The salt acts as an antiseptic and abrasive that removes plaque from the surface of the teeth. Drawing a waxed thin thread called **dental floss** backwards and forwards between the teeth

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removes food debris from in between the teeth and the crevices between teeth and gums, especially if the teeth are very close together. This is necessary because no amount of brushing, using a chewing stick, sponge, etc. can remove small food particles from these very small spaces.

Receiving regular expert attention

You should visit a dentist at regular intervals of six months to check on the condition of your teeth. It is also highly advisable to include in the diet foods and drinks rich in such minerals as calcium, phosphates and fluoride. Calcium and phosphates make teeth hard and durable, while fluoride strengthens the enamel and makes the teeth resistant to bacterial infection. Calcium phosphate is abundant in foods such as cheese, milk, beans, soya flour, herring (fish) and egg. Fluoride occurs naturally in drinking water in certain parts of the world. It is also added to toothpaste and drinking water in acceptable quantities.

Structure and functions of the digestive system of mammals

The digestive system of mammals consists of the **alimentary canal**, also called the gut, and its associated glands and organs (Figure 1.118). The alimentary canal is a muscular tube which consists of various regions as follows:

- mouth, gullet or oesophagus, stomach and **small intestine** (duodenum and ileum)
- **large intestine** (colon), appendix
- rectum and anus.

The glands and organs associated with the alimentary canal are the salivary glands, liver and pancreas.

While food is passing through the gut, various digestive juices are added to it. All of these, except bile, contain **enzymes**. Enzymes are biological catalysts that speed up the breakdown of food substances.

Mouth

Food is **ingested** (taken into the mouth) and **masticated** (chewed) with the teeth. Chewing breaks down solid food into smaller particles to provide a large surface area for enzyme action. Salivary glands produce a watery fluid called saliva which plays three important roles in the digestion of food:

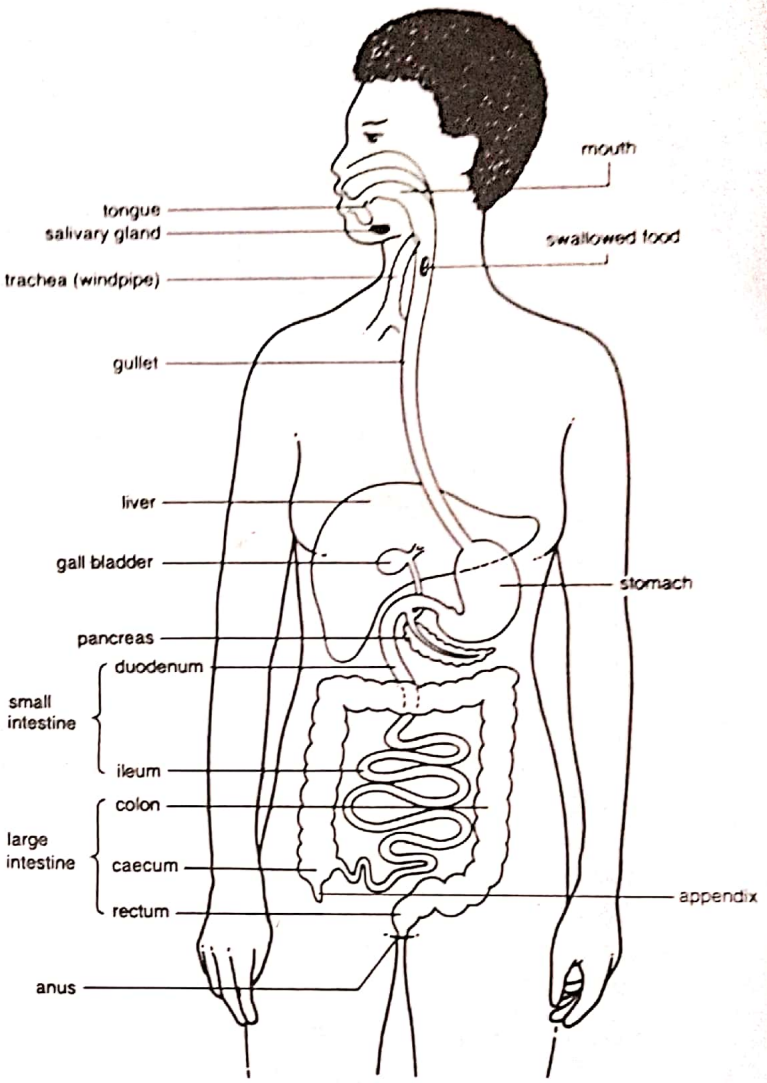


Fig 1.118 The human digestive system.

1 It mixes thoroughly with the food during chewing, making it soft and easier to swallow.
2 It contains an enzyme called **salivary amylase** that converts starch into maltose.
3 Saliva is slightly alkaline and keeps the pH of the mouth approximately neutral, providing the correct medium for salivary amylase.

The tongue rolls the food into a **bolus** (ball) and pushes it to the back of the throat from where it is swallowed. The hard palate of the upper jaw allows food to be crushed whilst the person can still breathe. The soft palate and the epiglottis help the food to pass down the oesophagus to the stomach (Figure 1.119).

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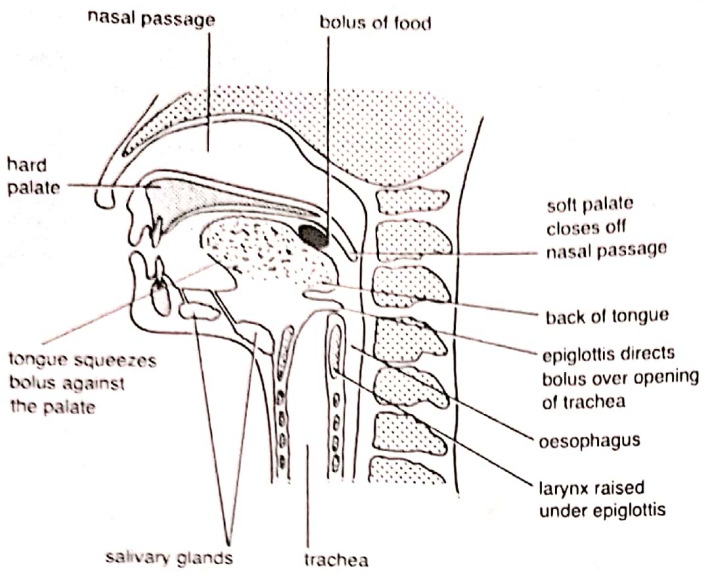


Fig 1.119 Vertical section through the human head to show swallowing action.

Oesophagus

This is a muscular tube that connects the mouth to the stomach. Food passes down the oesophagus under gravity and by **peristalsis** (alternate contraction and relaxation of the circular muscles of the gut) (Figure 1.120). Salivary amylase continues the conversion of starch to maltose in the oesophagus.

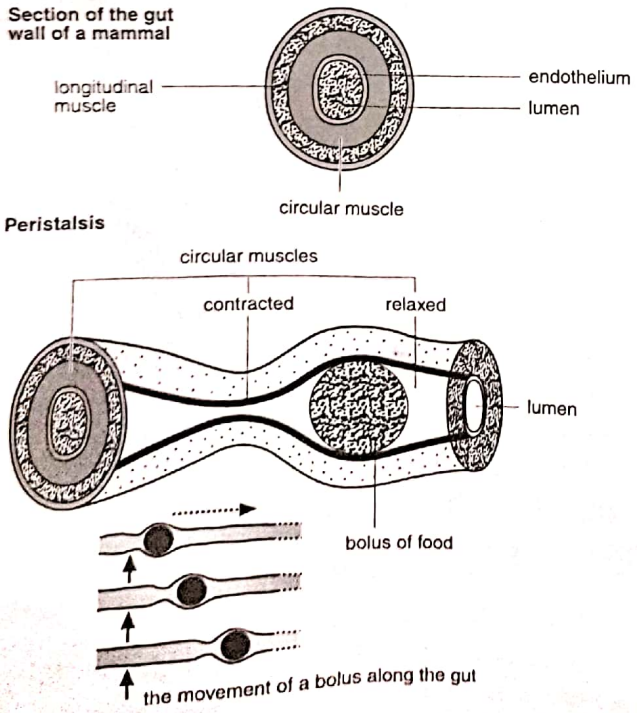


Fig 1.120 Peristalsis in the gut.

Stomach

The stomach is a sac-like organ at the upper left part of the abdominal cavity. It produces **gastric juice** which contains a number of substances:

- **mucus** – forms a protective inner lining to the stomach wall
- **hydrochloric acid** – sterilises food by killing bacteria; stops the action of salivary amylase; provides the correct acidic pH medium for action of the enzyme pepsin
- **pepsin** – a protease (enzyme) that converts proteins to polypeptides; secreted as inactive pepsinogen; pepsinogen is converted to active pepsin by the action of the hydrochloric acid.
- **rennin** – (in young mammals only) makes the liquid milk proteins solid so they remain in the stomach for pepsin to act on them.

Food remains in the stomach for 3–4 hours. During this time it is constantly churned by contraction of the stomach wall muscles. Chyme, a creamy-white semi-solid mixture of food substances, is formed by this process. Some substances, such as glucose and alcohol, are absorbed from the stomach into the bloodstream.

Duodenum

The pyloric sphincter muscles of the stomach relax periodically and the chyme passes a little at a time into the duodenum. The presence of chyme in the duodenum stimulates the wall of the duodenum to release the hormone **secretin** into the bloodstream. Secretin then stimulates the gall bladder to release bile and the pancreas to release **pancreatic juice** into the duodenum.

Bile

Bile is alkaline (contains sodium hydrogencarbonate) and raises the pH of the chyme. It **emulsifies** fats by changing large fat globules into many small fat droplets. Organic salts (sodium glycocholate and taurocholate) cause this emulsification. Emulsification increases the surface area of the fat, making digestion of fat by enzymes more efficient.

Bile also contains excretory materials from the breakdown of red blood cells. The bile pigments, bilirubin and biliverdin, are derived from broken down haemoglobin. These pigments give bile its green colour.

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Pancreatic juice

This is also alkaline and therefore raises the pH of chyme. It contains the following enzymes:

- **amylase** – converts starch to maltose
- **trypsin** – converts proteins to polypeptides and polypeptides to peptides; secreted as inactive trypsinogen; another enzyme, enterokinase, converts trypsinogen to trypsin and is secreted by the wall of the ileum
- **lipase** – converts fats to fatty acids and glycerol.

All these enzymes digest food as it passes through the duodenum and into the ileum.

Ileum

The walls of the ileum secrete the following enzymes that complete the digestion process:

- **lipase** – converts any remaining fats into fatty acids and glycerol
- **maltase** – converts maltose to glucose
- **lactase** – converts lactose to glucose and galactose
- **sucrase** – converts sucrose to glucose and fructose
- **erepsin** – converts peptides to amino acids
- **enterokinase** – converts trypsinogen to trypsin.

The small molecules of glucose, amino acids, fatty acids and glycerol are the end products of digestion in mammals. They are **absorbed** in the ileum which is well adapted for the process. The ileum is very long so that food takes a long time to pass through. Its inner surface is folded, forming thousands of microscopic projections called **villi** (singular: villus) (Figure 1.121). The villi vastly increase the surface area of the ileum and facilitate the absorption process. During absorption molecules of glucose, amino acids, fatty acids and glycerol move from the ileum across its wall into the bloodstream by a physical process known as diffusion.

> **Diffusion** is a physical process by which particles such as molecules and ions move from a region of higher concentration to that of lower concentration.

The simple sugars and amino acids diffuse into the blood. Some of the fatty acids and glycerol go into the blood from the ileum but most are absorbed into lymph vessels (lacteals) in the villi. They are carried in the lymph to the neck where the lymph drains into the blood. Undigested food, mainly cellulose, passes into the colon.

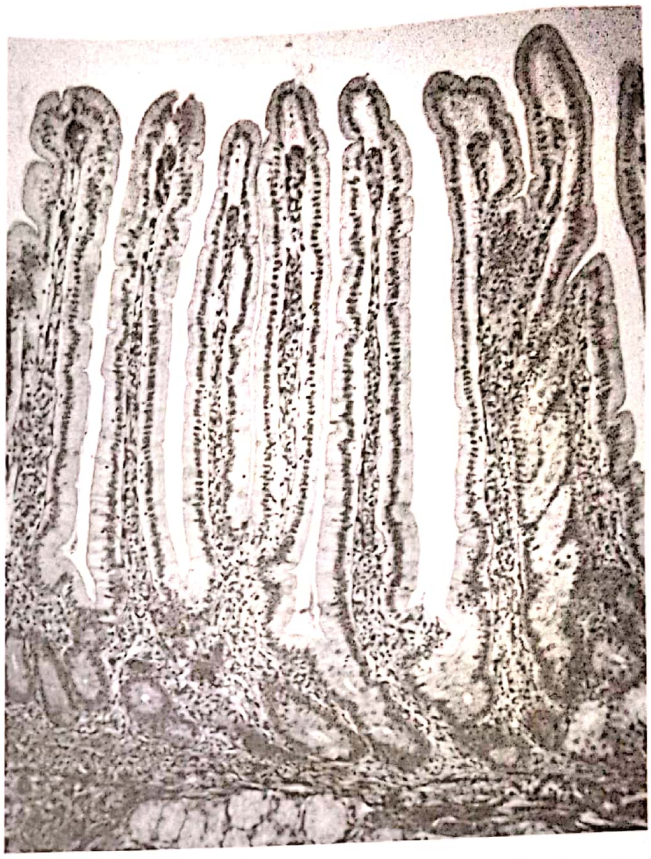


Fig 1.121 A section through part of the ileum showing villi.

Large intestine

Much water is absorbed from the undigested food in the large intestine (colon). Bacteria in the colon digest the cellulose and produce vitamins B and K which are absorbed and used in the body. The caecum and appendix are greatly reduced in humans and do not seem to perform any significant role in digestion. When water has been removed from the undigested food remains, the waste becomes semi-solid and is called **faeces**.

In herbivores, e.g. rabbits, the appendix and caecum are greatly enlarged (Figure 1.122). Here bacteria digest much of the cellulose into glucose, some of which is absorbed and used by the animal.

Rectum and anus

The faeces move into the rectum, where they are stored and periodically released via the anus. The removal of faeces from the rectum is called **egestion**.

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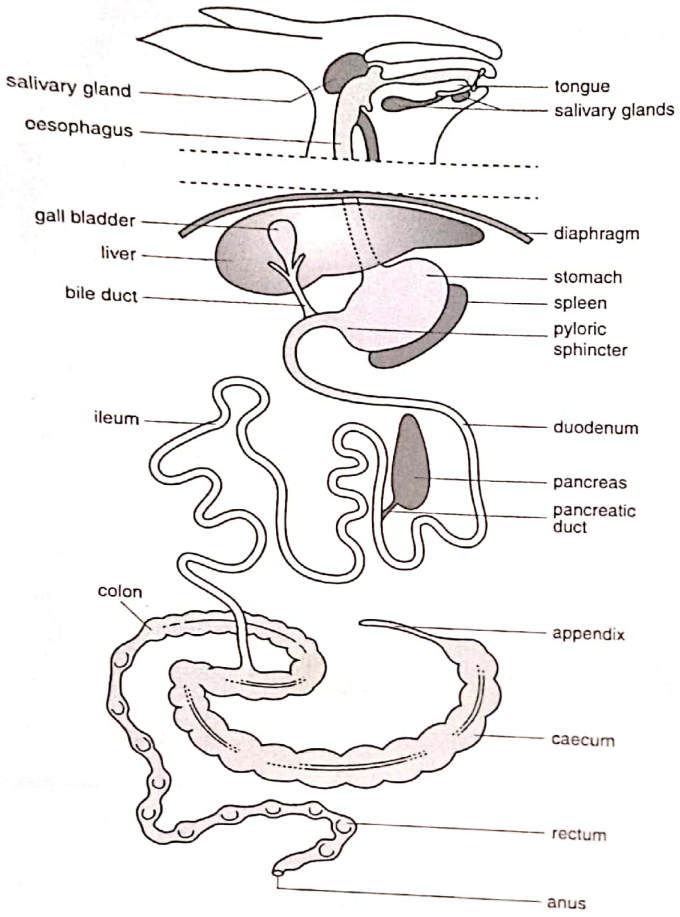


Fig 1.122 Alimentary canal of the rabbit.

ACTIVITY 4 Studying the digestive system of mammals

1 Your teacher will dissect a small mammal, e.g. guinea pig or rabbit.
2 Draw the dissection using Figure 1.122 as a guide.
3 Label the parts of the alimentary canal, the glands and organs associated with digestion.
4 *Work in groups* to discuss the functions of each part you have labelled. Write down these functions.

ACTIVITY 5 Studying digestion in mammals

1 Draw a table like the one in Table 1.40 on a large piece of paper.
2 Fill in the details of digestion in mammals.

Table 1.40

Region	pH	Secretion	Activities
mouth	7.0	Saliva	teeth break down solid food into smaller pieces salivary amylase converts starch to maltose
stomach			
duodenum			
ileum			

Ruminants and non-ruminants compared

Mammals, such as humans and rabbits, have a simple stomach which consists of only one chamber. They are known as **non-ruminants**. Other mammals, such as sheep and cows, have a more complicated stomach consisting of four chambers (Figure 1.123). These animals are known as **ruminants**. The first and largest chamber is called the **rumen**. Food enters this chamber when it is first swallowed. In the rumen the food is fermented by anaerobic bacteria which break down the cellulose. The food then passes to the **reticulum** where it becomes known as cud. This is regurgitated and chewed again. When the cud is swallowed it passes to the **omasum** where much of the water is reabsorbed. The food then passes into the **abomasum** (true stomach) where normal gastric secretions digest the proteins in the food. Chyme is formed which passes into the duodenum.

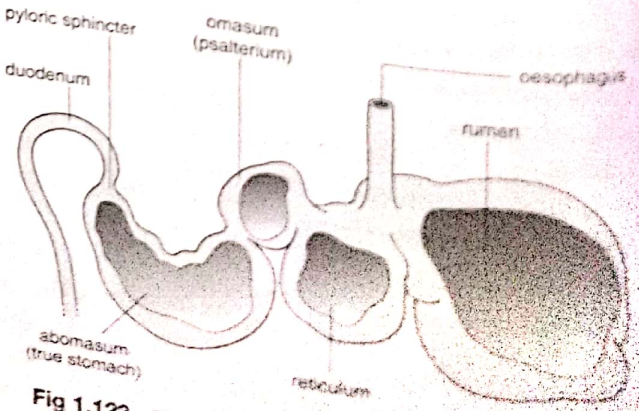


Fig 1.123 The four-chambered stomach of a cow.

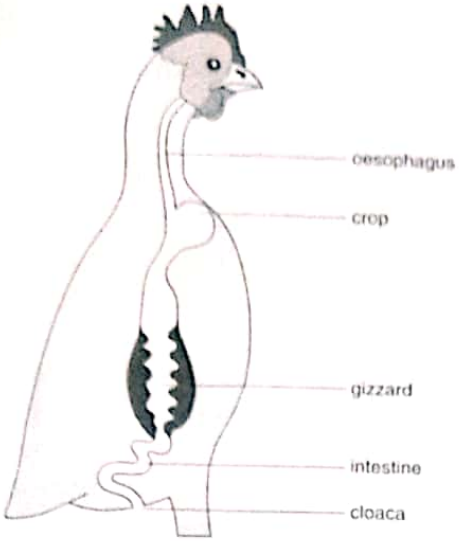


Fig 1.124 Alimentary canal of the domestic fowl.

Digestion in birds

In birds such as the domestic fowl, which is omnivorous, the stomach is divided into two parts, namely the **crop** and **gizzard**. Food is stored in the crop and ground up in the gizzard with the aid of small stones, before it passes into the intestine (Figure 1.124).

Digestion in mammals

Digestion is the mechanical and chemical breakdown of food into molecules small enough for the body to absorb. This is the second main stage of food processing following ingestion.

The digestion of various food substances is summarised in the following sections.

Digestion of carbohydrates

Digestion of carbohydrates starts in the mouth. The salivary glands secrete saliva which mixes with the food. The saliva contains salivary amylase (ptyalin) which changes starch into maltose sugar.

$$\text{Starch} \xrightarrow{\text{salivary amylase}} \text{Maltose sugar}$$

With the help of the tongue the food is rolled into a bolus and then swallowed. The food enters the stomach and remains in the stomach for about 1–4 hours. The stomach secretes gastric juice containing HCl. The stomach churns the food to form chyme. From there the food is sent into the duodenum. The liver secretes bile to neutralise the chyme. The pancreas also secretes the pancreatic juice containing pancreatic amylase. The pancreatic amylase changes starch into maltose sugar.

$$\text{Starch} \xrightarrow{\text{pancreatic amylase}} \text{Maltose}$$

The food moves into the ileum. The walls of the ileum contain the enzyme maltase which finally changes maltose into glucose.

$$\text{Maltose} \xrightarrow{\text{maltase}} \text{Glucose}$$

Digestion of proteins

Digestion of proteins does not start in the mouth. The saliva lubricates (softens) the food. With the help of the tongue the food is rolled into a bolus and then swallowed. The food enters the stomach and remains in the stomach for about 1–4 hours. The stomach secretes gastric juice containing HCl. The stomach churns the food to form chyme. Digestion of proteins starts in the stomach. The walls of the stomach secrete the enzyme pepsin. Pepsin changes proteins into peptones.

$$\text{Proteins} \xrightarrow{\text{pepsin}} \text{Peptones}$$

The food is sent to the duodenum. The liver secretes bile to neutralise the chyme. The pancreas also secretes pancreatic juice containing trypsin. Trypsin changes proteins and peptones into amino acids.

$$\text{Proteins} \xrightarrow{\text{trypsin}} \text{Amino acids}$$

Digestion of fats

Digestion of fats does not start in the mouth or the stomach. The saliva lubricates the food. With the help of the tongue the food is rolled into a bolus and then swallowed. The food enters the stomach and remains in the stomach for about 1–4 hours. The stomach churns the food to form chyme. The food is sent into the duodenum. The liver secretes bile to neutralise the chyme. The bile also helps to emulsify the fats.

The pancreas secretes pancreatic juice containing lipase. Lipase changes fats into fatty acids and glycerol. The food moves to the ileum. Any remaining fats are changed by the lipase in the small intestine into fatty acids and glycerol.

$$\text{Fats} \xrightarrow{\text{lipase}} \text{Fatty acids + Glycerol}$$

Richmond

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Final products of digestion

- Carbohydrates = Glucose and Fructose
- Proteins = Amino acids
- Fats = Fatty acids and Glycerol.

Absorption of digested food substances

This refers to the uptake of small nutrient molecules by the body. It is the third main stage of food processing, following digestion.

The small molecules of glucose and amino acids diffuse through the capillaries of the villi of the small intestine and are sent to the liver by the hepatic portal vein. The small molecules of fatty acids diffuse into the lymph capillaries which join to form the lacteal.

Uses of digested food

The end products of digestion are **assimilated** (taken up) by cells in various parts of the body. Glucose and other monosaccharides move into the blood by diffusion and enter the liver via the hepatic portal vein. In the liver excess glucose is converted into glycogen and stored. Some of the monosaccharides enter body cells where they are respired to release energy in the form of ATP for life activities.

Amino acids are also taken up into the bloodstream by diffusion from where they enter the liver via the hepatic portal vein. Some enter body cells where they are used to form proteins for growth, repair of damaged or worn out tissues and formation of enzymes, hormones, etc. Excess amino acids are deaminated in the liver to form urea which is excreted.

Fatty acids and glycerol recombine to form fats which then enter the lymph system before entering the bloodstream at the base of the neck. They are stored as fat or respired to yield energy.

Disorders and diseases of the human digestive system

Stomach ulcer

Ulcers in the stomach are called gastric or stomach ulcers. The direct cause of peptic ulcers is the destruction of the gastric lining of the stomach by HCl. Infection with the bacterium Helicobacter pylori is thought to play an important role in causing stomach ulcers.

Symptoms of stomach ulcers include:

- burning feeling in the stomach area
- heart burn
- loss of appetite and weight
- recurrent vomiting
- blood in the stools
- anaemia.

Indigestion

A disease or an ulcer in the digestive tract might cause indigestion. However, for most people, it is the result of eating too much, eating too fast, eating too many high fat foods or eating during stressful situations. Nearly everyone has had indigestion at one time.

Symptoms of indigestion include:

- belching and gas
- bloating (full feeling)
- heart burn
- abdominal pain
- nausea
- vomiting
- diarrhoea.

Lactose intolerance

This is a genetic trait that causes some people to gradually make less lactase as they reach their teens or early twenties. As a result, there is an inability to digest and absorb the sugar in milk. The individuals become increasingly lactose intolerant.

Symptoms of lactose intolerance include:

- diarrhoea
- gas
- abdominal pain
- bloating
- poor balance and co-ordination
- sleepiness
- poor judgement
- depression
- impaired memory and learning ability
- confusion and poor concentration
- flashbacks
- panic attacks
- loss of appetite
- hormonal changes
- danger to heart, liver and kidneys.

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Effects of food additives

Some of the effects that can be caused by food additives are:

- allergies
- contact dermatitis
- brain tumours
- bladder tumours
- triggering asthma
- chromosomal damage
- abdominal pain
- indigestion
- vomiting
- cancer.

Effects of food preservatives

Examples of the effects of food preservatives are:

- food asthma
- can lead to attention deficit hyperactivity disorder (ADHD) in children.

Effects of some drugs

Drugs taken for medical purposes should always be taken at the correct time and in the correct dosage, as prescribed by a health care professional. Sometimes people abuse drugs, such as psychotic or performance enhancing drugs, which they take for non-therapeutic or non-medical reasons. Examples of such drugs are amphetamines, barbiturates, benzodiazepines, cocaine, methaquinone and opium alkaloids. Some effects caused by abuse of drugs include:

- physical harm, e.g. liver damage, death
- psychological harm, e.g. drug addiction
- social harm, e.g. criminal penalty.

Effects of alcohol

Alcohol is a potent central nervous system depressant, with a range of side effects. The amount of alcohol consumed and its strength determine the extent of intoxication. Initially, alcohol generally produces feelings of relaxation and cheerfulness, but further consumption can cause the following effects:

- dehydration
- lowered inhibitions
- confusion
- memory impairment
- blurred vision
- coordination problems
- hangover
- stupor
- coma
- death.

The liver

The liver is a large, reddish-brown organ situated at the upper part of the abdominal cavity, just below the diaphragm, partly overlapping the stomach. It weighs a little over 1 kilogram in adult humans. Attached to it is a small sac-like structure called the gall bladder in which bile is stored. The bile is released into the duodenum and plays a part in digestion.

The liver has a rich supply of blood via the hepatic artery from the heart. The hepatic portal vein transports blood containing digested food directly from the small intestine to the liver. The digested food is 'screened' by the liver before it is sent to the rest of the body. The liver is spongy in texture because it is composed of masses of small cells, numerous small passages and blood vessels. The liver is also made up of a number of lobes which increase its surface area to enable it to function efficiently.

Functions of the liver

The liver has a central role in the metabolism of the body and carries out several functions (Figure 1.125).

- **Digestion** – the liver plays a part in digestion of food in the alimentary canal by producing bile. Bile salts emulsify fats in the duodenum so lipase can digest them.
- **Storage** – the liver changes excess glucose from the gut into **glycogen** and stores it as a food reserve. It stores vitamins A, D, K, and a product of vitamin B_{12} necessary for the formation of red blood cells in the bone marrow. It also stores some minerals such as iron.
- **Destruction of old red blood cells** – worn out red blood cells are broken down and bile pigments and iron are produced from the haemoglobin.
- **Deamination** – excess amino acids in digested food are deaminated by removal of the amine group ($-NH_2$) from the amino acid molecule. Some of the products of deamination are respired, while the rest are converted to urea which is subsequently excreted by the kidneys.
- **Detoxification** – the liver makes poisonous substances (toxins) harmless and non-toxic to the body. Alcohol and drugs are among the substances broken down by the liver. In post-mortem examinations the livers

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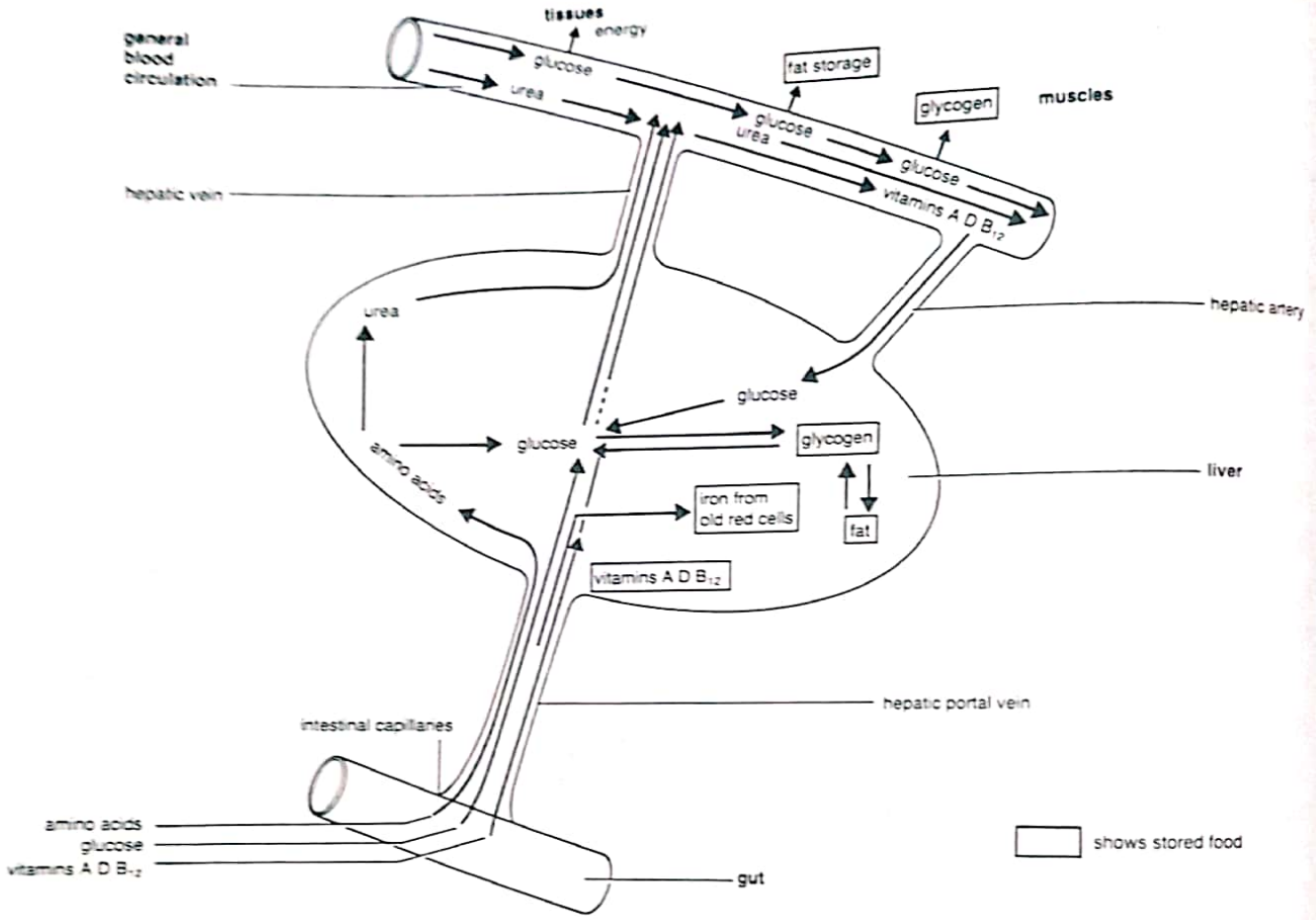


Fig 1.125 The liver with its blood supply and connections with the intestine.

of alcoholics and regular drug users are found to be shrunken in size compared to healthy livers.

- **Heat production** – the numerous chemical reactions that occur in the liver produce heat. This is evenly distributed in the body by the flow of blood. It contributes to the maintenance of normal body temperature of mammals. When the body is cold, metabolism in the liver increases to produce heat.
- **Control of blood glucose level** – excess glucose in the blood is converted to glycogen in the cells of the liver under the influence of a hormone produced by the pancreas called insulin. The glycogen is stored in the cells of the liver and changed back into glucose when the blood glucose level falls.
- **Production of plasma proteins** – the liver produces certain proteins found in blood plasma, including fibrinogen which is necessary for clotting of blood.
- **Metabolism of fats** – the liver changes excess fats into glycerol and fatty acids. These are oxidised to yield energy for life activities.
- **Excretion** – green and yellow pigments produced from the breakdown of old red blood cells, and excess cholesterol, are excreted in bile into the duodenum. It is the bile excreted into the intestine that gives the characteristic colour and smell to human faeces.
- **Destruction of hormones** – the liver destroys hormones when they enter it, stopping them from unlimited action.

Disorders and diseases of the liver

Cirrhosis

Excessive intake of alcohol over a long period adversely affects the normal functioning of the liver. Large amounts of alcohol in the human body may cause **cirrhosis**. This is a disease in which the normal liver cells are replaced by abnormal fibrous tissue which causes the liver to become hardened. The abnormal fibrous tissue does not perform the normal functions of the liver. Blood vessels leading from the intestine to the liver may become blocked, causing blood from the

small intestine carrying many poisonous substances to by-pass the liver into the body, leading to poisoning of the body. This disease leads to death.

Symptoms of cirrhosis include:

- jaundice
- gallstones
- intense itching
- fluid retention in the legs and abdomen.

Jaundice or icterus

The various bile substances are normally in solution, but sometimes they form solids called **gall stones** in the gall bladder or bile duct. These may block the bile duct and stop the flow of bile into the duodenum. Bile pigments may subsequently find their way into the bloodstream. One effect of this is that the skin and the whites of the eyes turn yellow. This is a type of **jaundice**. Jaundice can also be caused by the liver not functioning properly as a result of certain diseases, such as cancer of the liver and viral **hepatitis**. A patient suffering from viral hepatitis experiences frequent occurrences of sickness, fever and abdominal pains. The symptoms may disappear after a few weeks but the person remains weak for several months. The virus lies dormant in the liver so the disease may recur later, sometimes after several years.

Causes of jaundice are:

- malaria
- hepatitis (an inflammation of the liver)
- cirrhosis
- pancreatic cancer
- inadequate blood flow to the liver.

Symptoms of jaundice include:

- yellow discolouring of the skin, whites of the eyes and mucus membranes
- dark urine
- light-coloured stools
- abdominal pain
- nausea
- itching.

Effects of liver diseases on economic activities

The working population is reduced by deaths from liver diseases. People need to be healthy and strong to carry out activities, such as farming, fishing, trading, driving, factory and office work, etc. Illness caused by liver disorders prevents people from going to work and reduces their performance. This results in lower productivity and adversely affects the national economy.

Self check

For questions 1 to 6, choose the letter that refers to the correct option.

1 Bile emulsifies fats. This means the bile:
   A destroys fats
   B converts fats to fatty acids and glycerol
   C breaks down large fat globules into small fat droplets
   D prevents enzymes from digesting fats

2 In which parts of the alimentary canal is chyme found?
   A oesophagus and stomach
   B stomach and duodenum
   C duodenum and ileum
   D ileum and colon

3 The presence of villi in the ileum is to:
   A speed up the process of digestion
   B keep food in the ileum for a longer time for digestion to be completed
   C secrete digestive enzymes
   D increase the surface area of the ileum for absorption

4 Which of the following teeth are replaced by the diastema in herbivores?
   A incisors only
   B canines only
   C incisors and canines
   D canines and premolars

5 Which of the following methods of dental care is best for removing food debris from in between the teeth?
   A dental floss
   B toothbrush and paste
   C sponge
   D chewing stick

6 The main function of the gizzard in a domestic fowl is to:
   A store the food
   B synthesise vitamin B
   C grind the feed
   D secrete digestive juices

7 a) Draw a large labelled diagram of the vertical section of a named tooth of a mammal.
   b) State the names and functions of the types of human teeth.

8 a) Describe what happens to a meal of gari and beans mixed with palm oil as it travels from the mouth to the anus.
   b) State the uses of the end products of digestion in the body of mammals.

9 Distinguish between ruminants and non-ruminants.

10 Briefly discuss the ways by which humans can keep their teeth in a healthy condition.

11 a) Name two disorders of the liver.
   b) Briefly describe their causes and symptoms.

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6 Transport – diffusion, osmosis and plasmolysis

Learning objectives

After studying this unit, you should be able to:

1 explain the processes of diffusion, osmosis and plasmolysis
2 state the importance of the xylem and phloem tissues in plants.

Background information

Simple living organisms, such as unicellular organisms, do not need any elaborate structures to transport materials in their bodies. As the organism becomes multicellular and more complex, some cells are placed far away from the external surroundings of the organism. These cells cannot exchange materials with their external surroundings, creating a need for a transport system within the organism.

Humans have a transport system called the blood circulatory system consisting of the heart (a pump), blood vessels (tubes) and blood (a fluid). A second transport system, the lymphatic system, also carries materials around the body.

Flowering plants have two transport systems – xylem tissues for transporting water and minerals, and phloem tissues for transporting organic food substances.

Movement of substances in and out of cells

The cells of all multicellular organisms are surrounded by a watery fluid. The cytoplasm is also fluid, so substances in solution pass into and out of the cells in solution. Two ways by which substances move into and out of cells are **diffusion** and **osmosis**.

Diffusion

Diffusion occurs in substances where the molecules are able to move freely, i.e. liquids and gases.

> **Diffusion** is the movement of molecules from a region of high molecular concentration to a region of low molecular concentration until the molecules are evenly dispersed.

The difference in concentration between the two regions is called the **concentration gradient**. Diffusion will only occur when such a gradient exists, and the steeper the gradient, the faster the rate of diffusion. The rate of diffusion can also be accelerated by agitation (stirring) and heating. Both these actions increase movement of the molecules. Figure 1.126 illustrates how diffusion occurs.

Examples of diffusion

Substances can diffuse into and out of cells if the cell membrane is permeable to them. There are many examples of diffusion in living organisms, such as:

- diffusion of hormones out of endocrine glands
- diffusion of oxygen into the blood and carbon dioxide out of the blood in the lungs of mammals

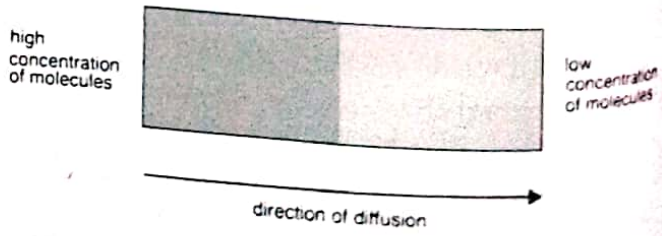


Fig 1.126 Diffusion.

- diffusion of carbon dioxide into the blood and oxygen out of the blood in the tissues of vertebrates
- diffusion of carbon dioxide into the leaf and oxygen out of the leaf through the stomata
- diffusion of some mineral salts from the soil water into root hair cells
- diffusion of oxygen into the cell and carbon dioxide out of the cell in unicellular organisms like *Amoeba*
- absorption of end products of digestion, e.g. glucose and amino acids, in the small intestine of mammals.

ACTIVITY 1 Demonstrating diffusion in a gas

1 Close all the windows and doors in the classroom.
2 Place a few drops of perfume in an evaporating dish in one corner of the room.
3 By smelling the perfume, trace its movement through the room.
4 Record your observations.
5 *Work in groups* to discuss what has happened

ACTIVITY 2 Observing diffusion in a liquid

1 Fill a large beaker with water.
2 Carefully drop a crystal of potassium permanganate into the water near to one side of the beaker.
3 Leave the beaker on the bench for at least 30 minutes and observe it at regular intervals. Be careful not to move the beaker.
4 Record your observations.
5 *Work in groups* to explain what has happened

Compare your results with the diagrams in Figure 1.127.

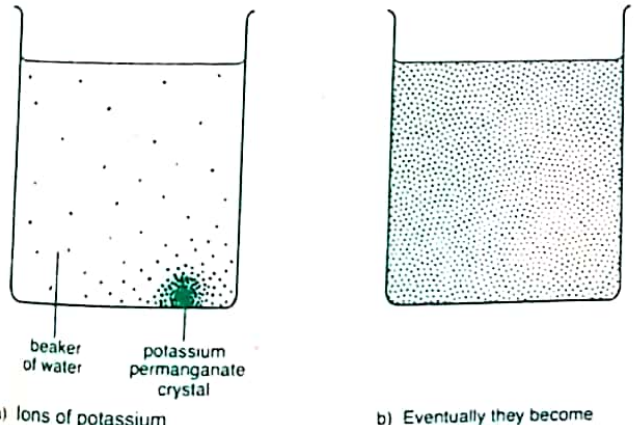


Fig 1.127 Diffusion in a liquid.

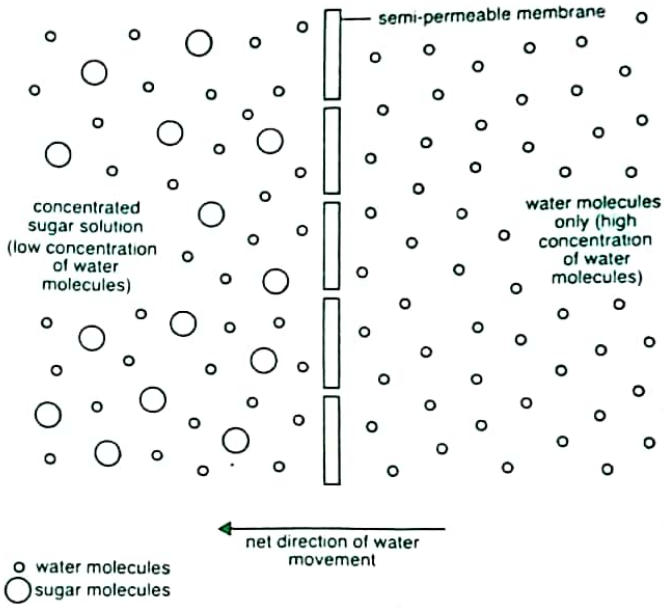


Fig 1.128 Osmosis.

Osmosis

Osmosis is sometimes referred to as a special kind of diffusion involving the movement of water (solvent) molecules.

Osmosis is the movement of water (solvent) molecules across a partially permeable membrane from a dilute solution (high concentration of water) to a more concentrated solution (low concentration of water).

The greater the difference in concentration between the two solutions, the faster the rate of osmosis. The rate also increases with a rise in temperature. Osmosis is illustrated in Figure 1.128.

ACTIVITY 3 Demonstrating osmosis in non-living tissue

1 Cover the end of a thistle funnel with cellophane and secure it tightly.
2 Pour 30 per cent sugar solution (dyed with food colouring) into the funnel so that it comes part way up the tube.
3 Mark the level of the sugar solution.
4 Suspend the thistle funnel in a beaker of water as shown in Figure 1.129.

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5 Observe the level of sugar solution at 1 hour intervals for about 6 hours.

6 What happens to the level in the tube?

7 Explain your result in terms of osmosis.

8 What type of membrane is the cellophane?

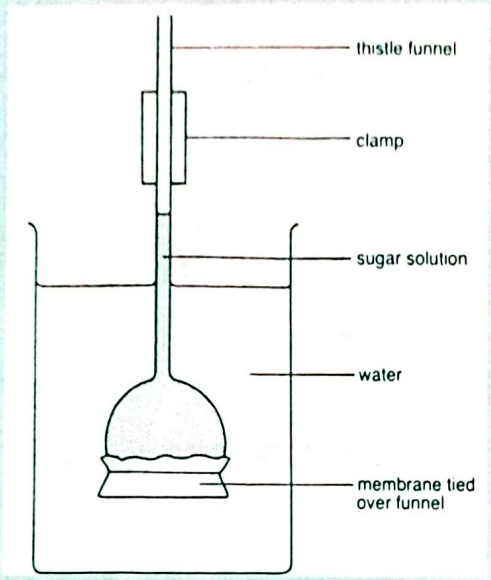


Fig 1.129 Demonstration of osmosis.

Osmosis in living tissues

In living cells water passes into and out of the cell across the cell membrane, depending on whether the surrounding medium is at a lower or higher concentration than that of the cell contents.

ACTIVITY 4 Demonstrating osmosis in a living tissue

1 Cut three cubes, with 5–10 cm sides, from a yam or cassava tuber.

2 Scrape out a cavity in each (Figure 1.130).

3 Put one cube in boiling water for about 5 minutes.

4 Put the base of each cube in small dishes containing a small amount of water.

5 Put some sugar solution into the cavities in the fresh cube and the boiled cube.

6 Leave the cubes for about 6 hours and then examine the cavities.

7 What did you observe?

8 Explain your observation.

9 Why was one cube boiled?

If an animal cell, such as a red blood cell, is placed in a solution that is more concentrated than the cell contents (e.g. strong sugar or salt solution) – the cell is in a **hypertonic** environment – the cell will lose water by osmosis and shrink. This is termed 'crenation'. If the same cell is placed in a solution that is less concentrated than the cell contents (e.g. distilled water) – the cell is in a **hypotonic** environment – then the cell will gain water by osmosis and swell. Eventually, the pressure will burst the cell (Figure 1.131). Animal cells are normally surrounded by a solution that is equal in concentration to the cell contents – the cells are in an **isotonic**

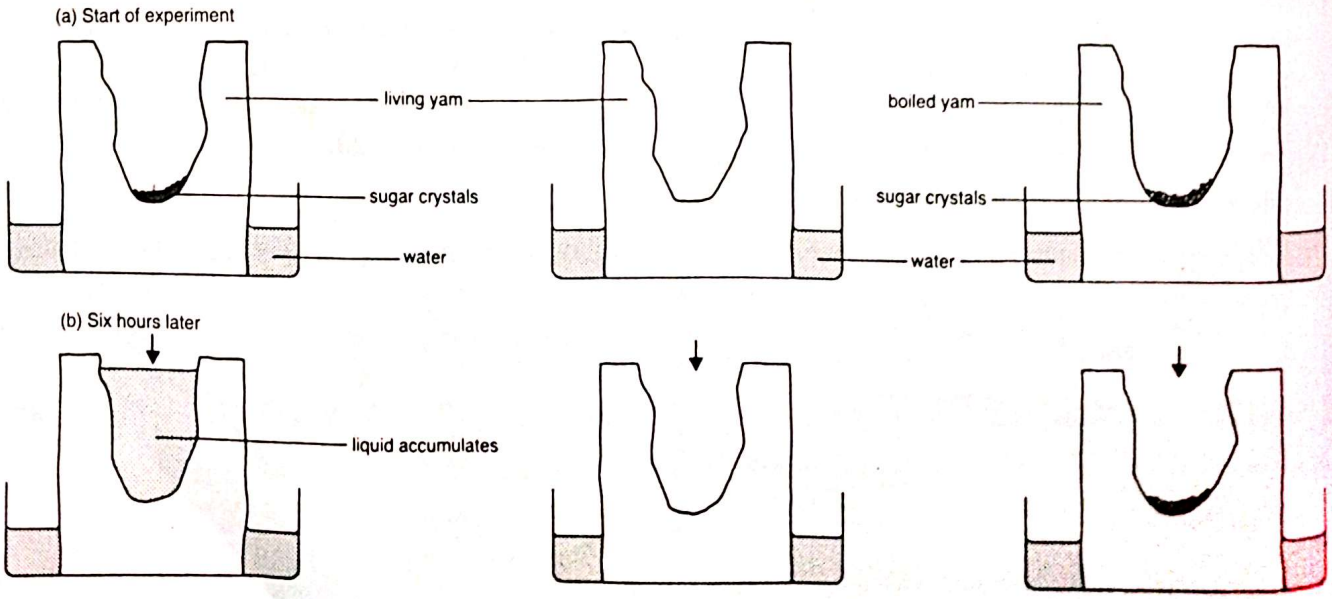


Fig 1.130 Osmosis in a living tissue.

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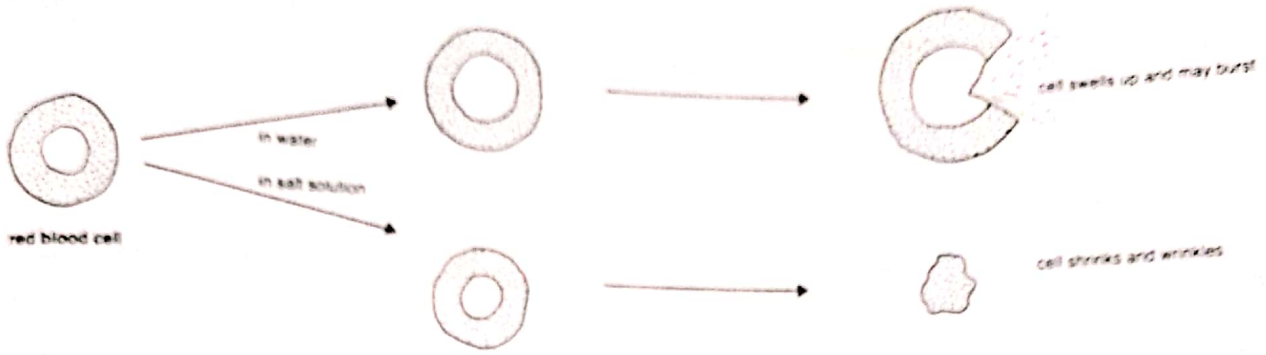


Fig 1.131 Osmosis in animal cells.

environment – thus the net movement of water is zero, i.e. no more water enters than leaves the cell.

If a plant cell, such as an onion epidermal cell, is placed in a solution that is less concentrated than the cell sap, the cell will gain water by osmosis until the pressure of water pushing outwards equals the pressure pushing inwards by the cell wall. At this stage, no more water enters and the cell is said to be **turgid**. Plant cells are normally maintained in this state, which helps to support the plant. If the same cell is put into a solution that is more concentrated than the cell sap, the cell will lose water by osmosis. The cell loses its turgidity and becomes limp and **flaccid**. Eventually, the cytoplasm shrinks away from the cell wall and the cell becomes **plasmolysed** (Figure 1.132).

Some examples of osmosis in living organisms are:

- absorption of water from the soil by roots of plants
- absorption of water in the colon (large intestine) of mammals
- absorption of water in the nephron of the kidneys of mammals.

ACTIVITY 5 Demonstrating plasmolysis in plant cells

1 Obtain a leaf of *Rhoeo*, *Zebrina* or *Spirogyra*.
2 Using a blade or scalpel, carefully strip off a piece of the upper epidermis. (With *Spirogyra*, place a few strands on a microscope slide.)
3 Place the piece on a microscope slide with a drop of 30 per cent sugar solution.
4 Immediately observe the slide under the microscope and repeat the observations every 2 minutes for 15 minutes.
5 Draw and label two cells and explain what has happened to them. Compare what you see with Figure 1.132.

The differences between diffusion and osmosis are summarised in Table 1.41.

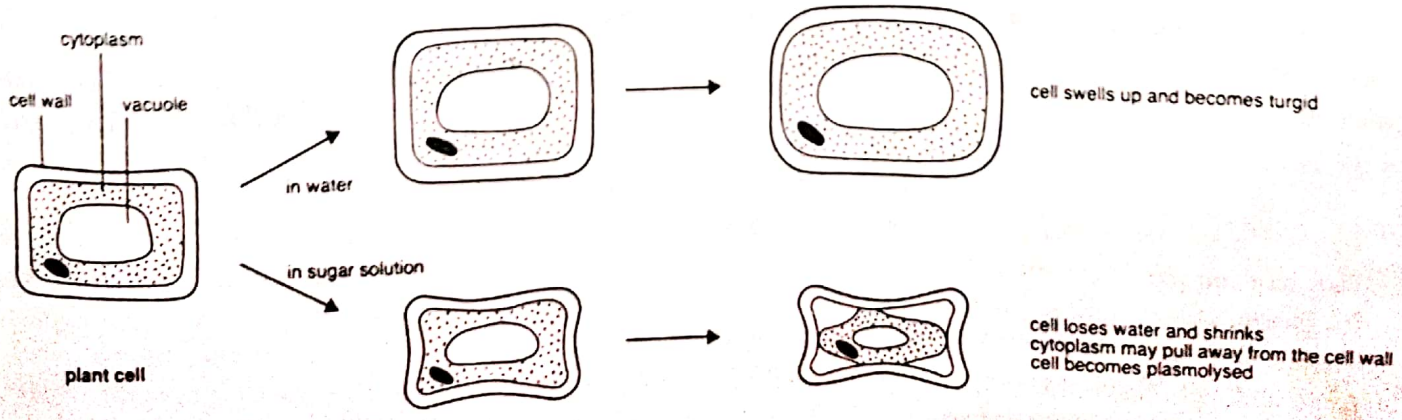


Fig 1.132 Osmosis in plant cells.

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Table 1.41 Differences between diffusion and osmosis

Diffusion	Osmosis
involves movement of any particle, i.e. both solvent (e.g. water molecules) and solute particles move	involves movement of only solvent particles (e.g. water molecules)
occurs in both gases and liquids	occurs in liquids only
no partially permeable membrane is required	a partially permeable membrane is required

Transport in flowering plants – xylem and phloem

The movement of dissolved substances in flowering plants includes movement of water and mineral salts from the soil through the roots and stems to the leaves, and movement of the products of photosynthesis from the leaves to growing regions and storage organs.

Absorption and transport of water and mineral salts

Vacuoles in the root hairs of a plant normally contain a higher concentration of solutes than the surrounding soil solution. Water therefore enters the root hairs by osmosis. As a result, their vacuoles become less concentrated than those of adjacent root cortex cells and water passes into these cells by osmosis. The water then moves through the root cortex from cell to cell by three different pathways. Most of the water flows along the cellulose cell walls, some travels in the cytoplasm, and the rest passes from vacuole to vacuole. Eventually, the water reaches the xylem vessels. The water then enters the xylem vessels by a process which is not yet fully understood. Figure 1.133 summarises this pathway.

The mineral salts necessary for healthy growth of a plant are found in ionic form, dissolved in the soil water surrounding the roots. Two processes are involved in their absorption:

- **Diffusion** is a passive process and can only occur when the concentration of a particular mineral element is greater in the soil solution than in the root hair cell sap. Many mineral elements are found in greater concentrations in cell sap than in the surrounding soil solution. These must be actively taken up by the plant.
- **Active transport** involves the use of energy in the form of ATP (produced in respiration) to move mineral ions into the root hair cells against their concentration gradient. Once absorbed, the mineral ions diffuse through the cortex cells and enter the xylem with the water.

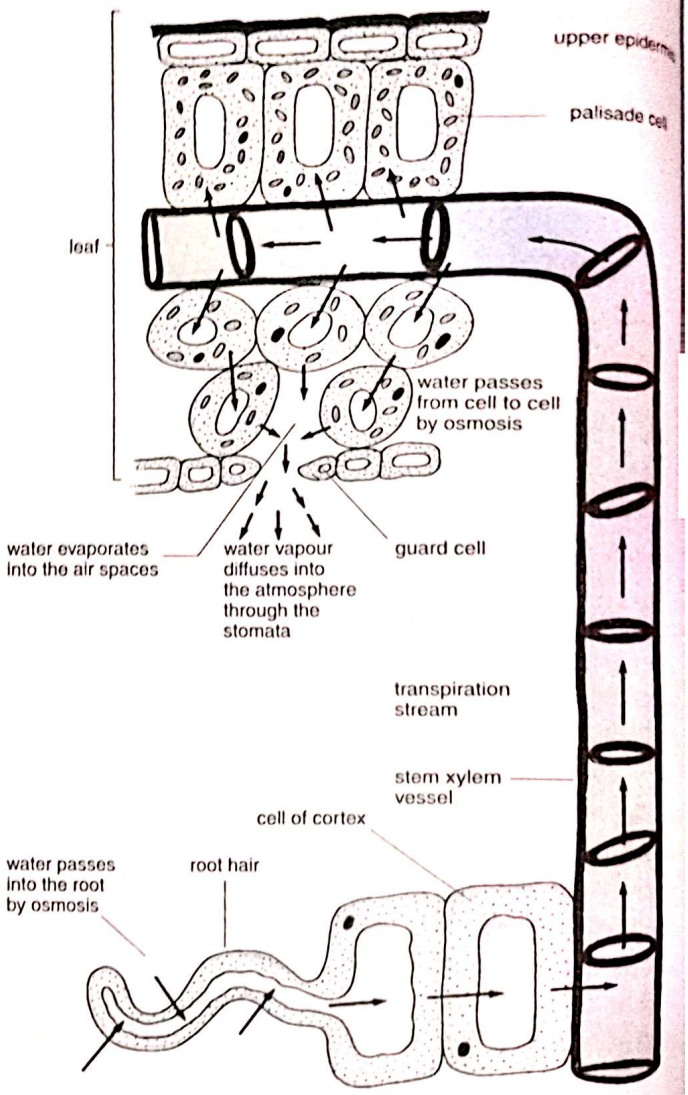


Fig 1.133 Summary of the transpiration stream.

Water is continuously lost from the leaves of plants in the form of water vapour. This is known as **transpiration**. The water vapour diffuses through the air spaces of the leaf and into the atmosphere. This is replaced by more water evaporating from the surfaces of the surrounding mesophyll cells into the air spaces. The solution in these mesophyll cells becomes more concentrated than that of their neighbouring cells. Water therefore passes from the latter to the former by osmosis. This continues until the xylem of the veins is reached. The xylem in the leaf veins has

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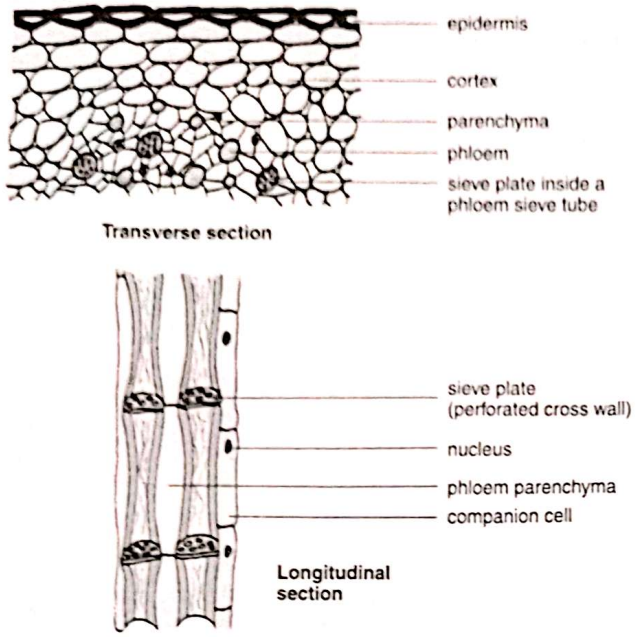


Fig 1.135 The phloem tissue.

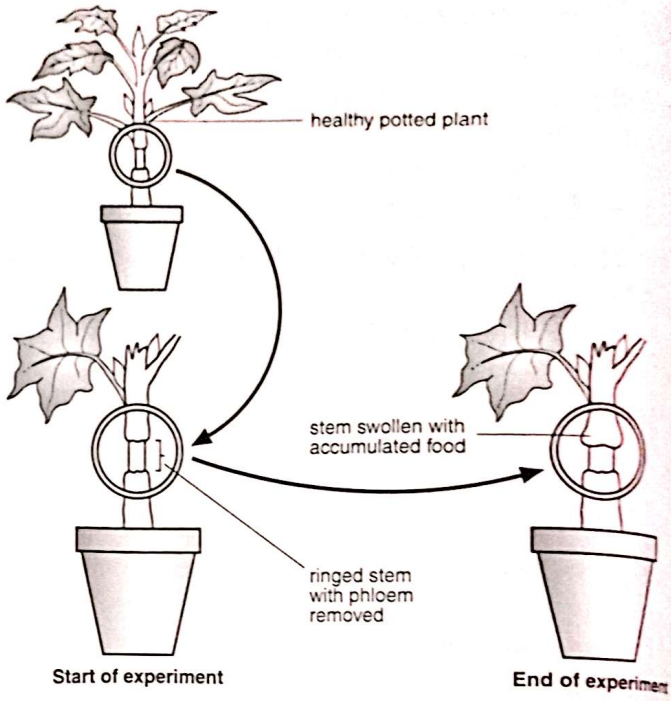


Fig 1.136 Results of the ringing experiment.

removal of a ring of bark and associated phloem from a tree. After a few hours a swelling is seen above the ring. If the contents of the swelling are analysed it will be revealed that they are mainly organic food substances, such as sugars. This means that it is the phloem tissue that transports organic food in flowering plants. Below the ring, the sugar concentration decreases. This shows that sugars are not able to move through the xylem.

ACTIVITY 8 The ringing experiment

1 Remove a portion of the bark and phloem from a healthy potted plant in the form of a ring 5 cm wide, leaving the xylem exposed and intact.

2 Observe for several hours.

3 Compare your observations with Figure 1.136. Explain the reason for the swelling above the ring.

ACTIVITY 9 Identifying the phloem tissues

1 Using a sharp razor blade cut thin transverse sections of the stem of a plant, such as water leaf or maize seedlings. Also, cut thin longitudinal sections.

2 Mount the cut sections on a clean slide, stain with aniline blue and cover with a cover slip.

3 Carefully observe the cut sections of the stem under the microscope and record your observations.

4 Draw and label your cut transverse and longitudinal sections using Figure 1.135 as a guide.

5 Which tissues are stained blue?

You will observe that only the phloem tissues are stained blue.

Self check

For questions 1 to 3, choose the letter that refers to the correct option.

1 Which one of the following statements best explains osmosis?
- A solvent molecules move from a weak solution into a strong solution
- B solvent molecules move from a weak solution into a strong solution across a partially permeable membrane
- C solute particles move from a strong solution into a weak solution
- D solute particles move from a weak solution into a strong solution across a partially permeable membrane

2 When particles move against their concentration gradient the process is referred to as:
- A diffusion
- B osmosis
- C plasmolysis
- D active transport

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3 Which one of the following is an example of diffusion in mammals?

A movement of urine from the kidney into the urinary bladder

B movement of saliva from the salivary glands into the buccal cavity

C sweating

D gaseous exchange in the alveoli of the lungs

4 a) State three differences between diffusion and osmosis.

b) State two examples of diffusion in plants.

5 Explain what would happen to a plant cell if it was placed for a long time in a solution which was stronger than its cell sap?

6 Describe how water and mineral salts travel in the stem of flowering plants.

7 Explain how manufactured food substances are transported from one part of the plant to another.

1 Forms of energy and energy transformation

Learning objectives

After studying this unit, you should be able to:

1 distinguish between various forms of energy and modes of transformation
2 discuss the conservation of energy and efficiency of energy conversion.

Background information

Energy is essential for life processes, chemical reactions and industrial activities. Nations that have enormous reserves of energy are ranked high among wealthy nations. Energy is available in various forms in nature but requires high scientific and technological knowledge, skills and positive attitudes to tap it, conserve it and transport it into homes and workplaces for use. It is important for us to understand the various forms of energy, and its sources and applications in our daily activities.

The sun is the main source of energy for the Earth. The radiant energy from the sun is the source of energy for photosynthesis in plants. In this process energy in the form of glucose is stored for the plant and other consumers such as animals.

The energy from the sun is scientifically utilised to power gadgets, such as solar lamps, electronic calculators and spacecraft, and also to help conserve energy in solar cells for use, especially during the night.

In Junior High School we discussed the different forms of energy. In the discussion solar, chemical, electrical and mechanical energy were highlighted and how each is converted from one form to the other.

In modern times photons in solar radiant energy are tapped with solar panels and stored in solar cells for use. This will be discussed fully in the next unit.

Forms of energy and energy transformation

In the eighteenth century an Italian Scientist called Count Allesandro Volta invented a simple cell which led to the inventions and innovations of other electric cells.

In the simple cell of dilute tetraoxosulphate (VI) acid (H_2SO_4) in a container the chemical reaction of the acid generates electrical energy. The acid serves as an electrolyte, the copper plate as the cathode and the zinc plate as the anode as shown in Figure 1.137.

Other cells, such as the Daniel cell, the wet and dry Lechlanche cells, have since been invented. Advanced forms of cells, such as the lithium cell, which produce 2.0–3.8 V and last as long as 3–5 years are on the market.

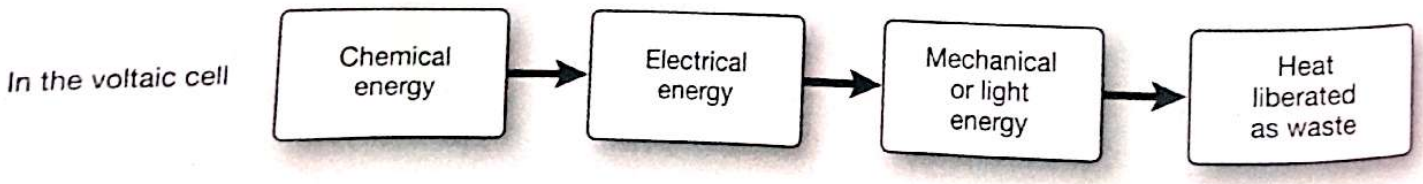


Fig 1.137 Energy transformations in a simple voltaic cell.

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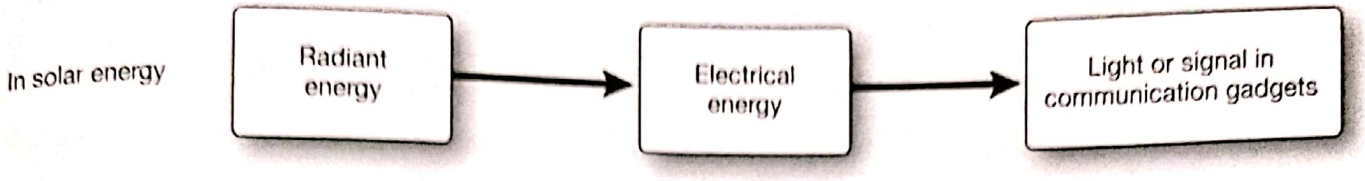


Fig 1.138 Conversion of solar energy.

The discovery of semiconductor substances, such as germanium and silicon, has led to the development of solar panels and solar cells which convert solar energy into electrical energy in order to power solar gadgets (Figure 1.138). In Ghana solar panels are widely used in solar villages in Eastern, Volta and the three Northern regions.

Fossil fuel

Fossil fuel is the deposition of organic matter in the soil over millions of years to produce crude oil.

Firewood, charcoal and wastes from fruits and seeds have been a traditional source of energy for cooking and baking in many homes. This is called **biomass**. Technology has led to the mining and fractional distillation of crude oil which has broadened the petrochemical industries (Figure 1.139).

Biomass is converted into biogas with digesters to produce biogas for domestic use (Figure 1.140).

Forms of energy

Potential energy

Potential energy is defined as the energy possessed by a body by virtue of its position relative to a reference point, such as the ground, or its position in a field of force. Potential energy may either be a gravitational potential energy or an elastic potential energy, e.g. found in shooting arrows from bows or springs.

Gravitational potential energy is determined by the mass of the body and acceleration due to the force of gravity reacting on the body.

$$\text{Potential energy} = \text{mass} \times \text{acceleration due to gravity} \times \text{height}$$

$$P = mgh$$

where m = mass, g = acceleration due to gravity and h = height from the object to the ground.

Elastic potential energy is defined by the product of the spring constant and the compression or extension of the elastic material, such as spring or elastic material.

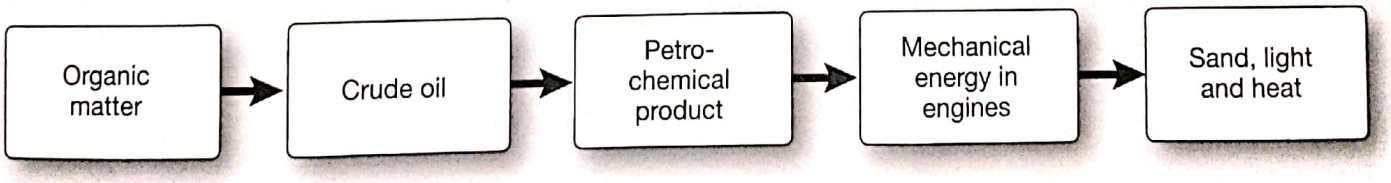


Fig 1.139 Energy transformations into crude oil and petrochemical products.

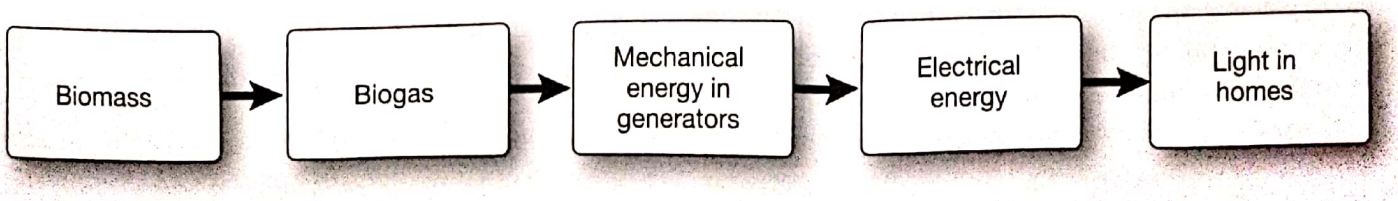


Fig 1.140 Energy transformations from biomass into light energy in homes.

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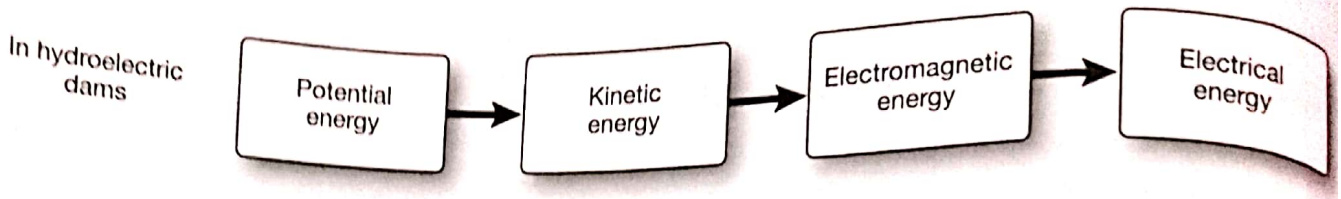


Fig 1.141 Energy transformations in hydroelectric dams.

Elastic potential energy = $\frac{1}{2}$ k × the extension or compression of the elastic material, where k is the elastic contant.

Kinetic energy

Potential energy can easily be converted into kinetic energy when, as a result of an external force, the object or system is set in motion.

$$KE = \frac{1}{2}mv^2$$

where m = mass and v = velocity of the object in motion.

Water stored behind a dam has a high potential energy that is released to flow to propel turbines with dynamos to convert mechanical energy into electrical energy (Figure 1.141).

Electrical energy

A massive flow of electrons generated as a result of mechanical or chemical reactions generates electricity to power domestic as well as industrial appliances in homes and workplaces, respectively.

Cellular respiration

Chemical energy is liberated from glucose during organic cellular respiration in plants and animals. This is the source of energy for plants and animals and is referred to as **tissue respiration**.

Other forms of energy

In Ghana thermal energy from the burning of crude oil or its by-products is used to generate electric energy to supplement the hydroelectricity generated from the Akosombo and Kpong dams, and in the near future from the Bui dam, which is under construction.

Electrostatic energy is produced by the collision of rain bearing clouds, releasing a flow of charged particles through the atmosphere which harm, in most cases, tall buildings and trees when the particles flow through them.

Renewable forms of energy, such as geothermal, sea wave related, wind and solar energy are being considered by governments for national development.

Conversion of energy

Energy can be transformed from one form into another. The flow charts above indicate how energy conversion occurs.

ACTIVITY 1 Energy transformations

1 *Work in groups* to represent the following energy transformations using drawings and flow charts:

a) solar energy to chemical energy in photsynthesis

b) electrical energy to light energy in a bulb

c) release of chemical energy from glucose during cellular respiration.

Conservation of energy and efficiency of energy conversion

Principle of conservation of energy

The **principle of energy conservation** states that energy is neither created nor destroyed but is transformed from one form into another.

Energy in any process is neither produced nor used up. In processes:

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Self check

1 Explain the following terms:
   a) voltaic cell
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2 Distinguish between energy from biomass and energy from a radiant source.

3 Draw a flow chart to demonstrate the energy transformations that happens in:
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4 Compare potential energy and kinetic energy and outline the similarities and differences between them.

5 Explain why crude oil as a fossil fuel can be linked to biomass as a source of energy.

6 Use a flow chart to demonstrate how the potential energy of water behind a dam is transformed into electrical energy for use in homes.

7 Explain how crude oil is converted into thermal energy at Aboadze in the Western region of Ghana.

8 Describe how energy is produced from cell respiration.

9 How is elastic energy transformed into kinetic energy in a bow and arrow?

10 Why is energy said to be conserved? Use flow charts to show the energy of transformation in photosynthesis and tissue respiration.

11 Explain the term 'efficiency of energy'.

12 Why is the efficiency of energy always less than 100 per cent in mechanical devices?

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1 Forms of energy and energy transformation

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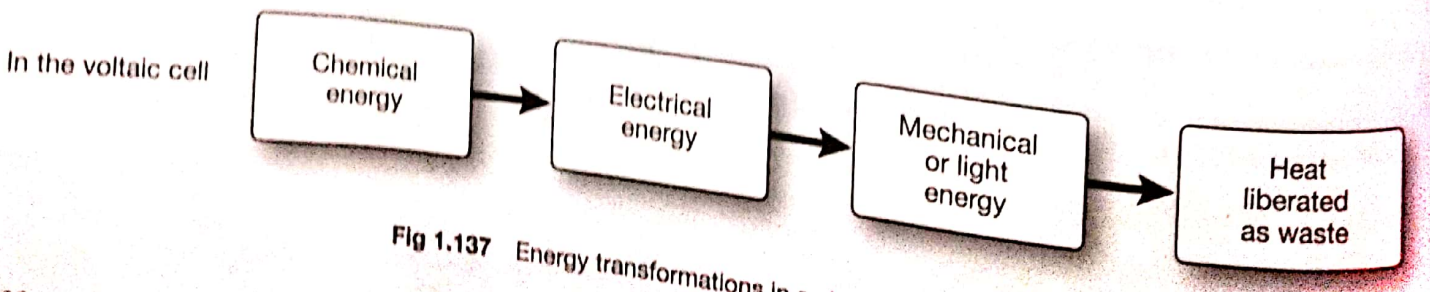


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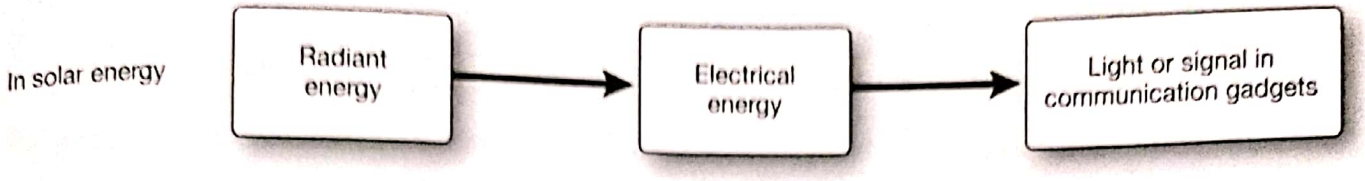


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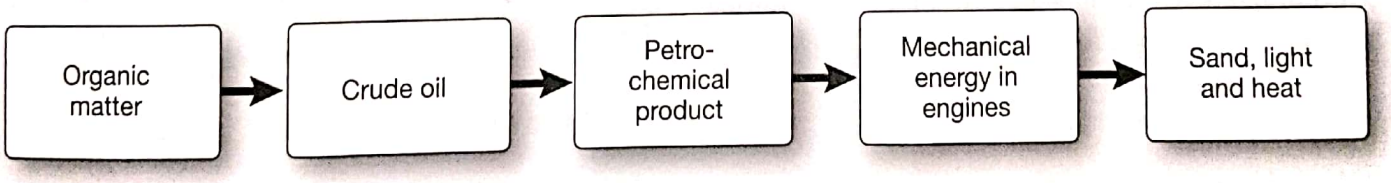


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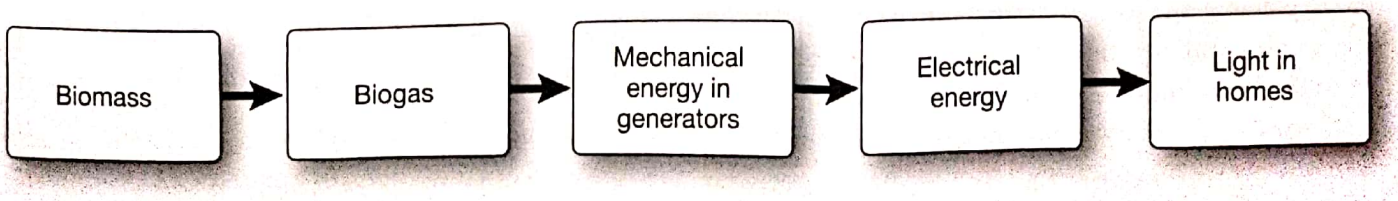


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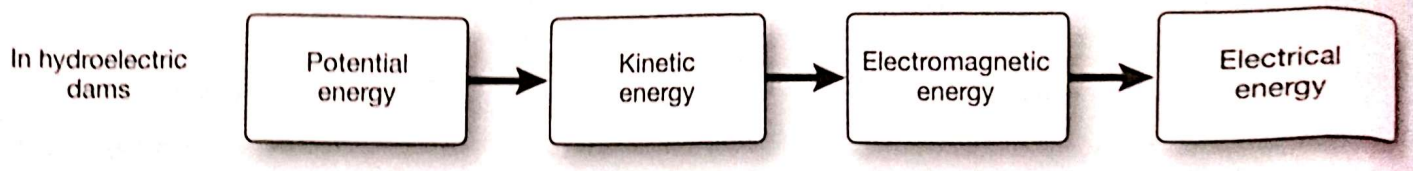


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2 Solar energy

Learning objectives

After studying this unit, you should be able to:

1 identify the uses of solar energy
2 document the use of solar energy in daily activities
3 model a solar heater and dryer.

Uses of solar energy

Our parents have depended on the radiant energy from the sun for preservation and conservation of grains, seeds and vegetables for many years. Sunbaked brick has been a useful architectural material for the construction of many buildings in many villages.

Plants through photosynthesis manufacture glucose which serves as a store of energy for both plants and some animals. In recent years the discovery of semiconductors made from silicon and germanium has led to the construction of solar panels to trap photons from solar energy and convert them into electrical energy to power homes, heat water and provide energy for electronic devices, such as digitised clocks and solar lamps (Figure 1.142).

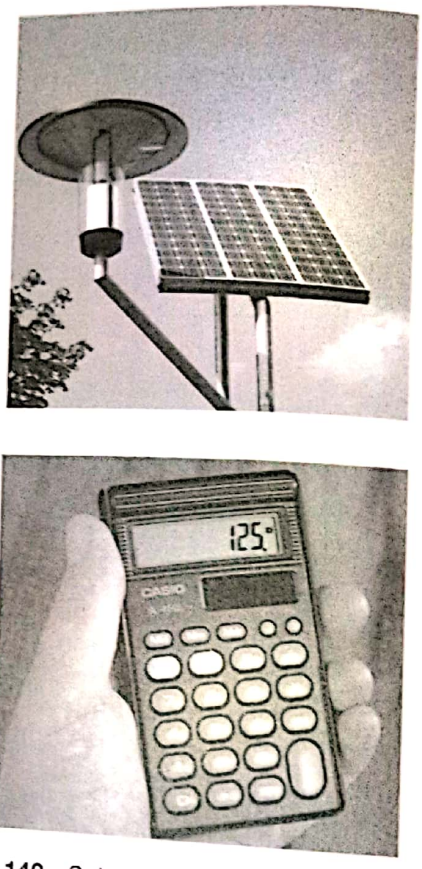


Fig 1.142 Solar energy devices **(a)** solar lamp **(b)** electronic calculator powered by solar panel.

Generation of electricity from solar panel/solar cells

Solar panels

A solar panel is a device which collects and transforms solar energy into electricity.

The device has the following features and respective functions:

- photovoltaic (PV) structure also referred to as the PV module
- solar thermal collector – traps heat from the solar radiation called photons
- solar hot water panels – use radiant energy to heat water for homes, institutions and hospitals
- solar lamps – have solar cells to store solar energy to provide light in lamps for homes.

The PV module is a collection of solar cells also known as photovoltaic cells (Figure 1.143). The cells are arranged into panels which are parallel to each other to convert photons into electrical energy.

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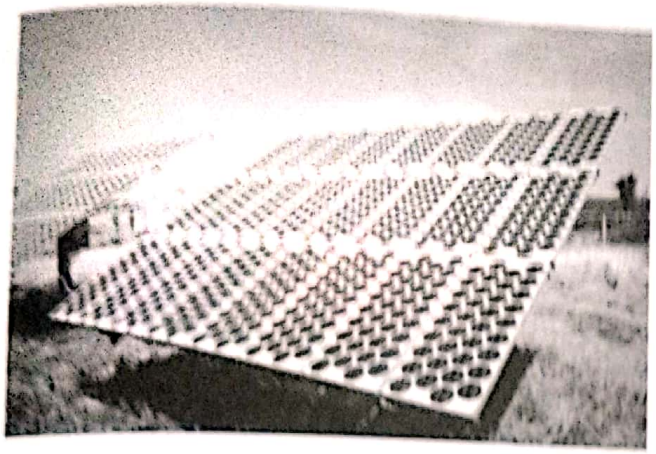


Fig 1.143 Photovoltaic module.

In the PV module a number of cells are mechanically assembled and wired to form a compact unit for installation. A solar panel has the following components:

- inverter
- batteries
- wiring.

A solar panel is used to produce electricity to pump water for irrigation, to charge photovoltaic cells, to produce light and to power some communication gadgets.

Solar cells

In this type of cell solar energy is converted into electrical energy and stored to produce an electromotive force which sets myriads of electrons into motion.

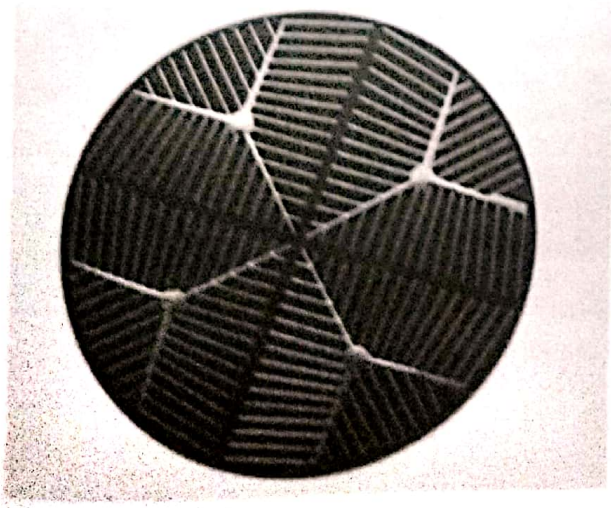


Fig 1.144 Solar cell.

The components of a solar cell are (*Figure 1.144*):

- encapsulate
- contact grid
- anti-reflective coating (AR coating)
- n-type silicon (negative)
- p-type silicon (positive)
- back cover (often glass).

How solar cells work

When radiant energy (photons) enter the encapsulate they enter the entire reflective layer, which is dark in colour. The photons travel from the anti-reflective layer to the lower layer of the cell.

In the lower layer the photons strike the silicon surface, which is also called the contact grid. At this stage enormous numbers of electrons are mobilised to flow. In the n-type silicon layer the free electrons are called the majority carrier and the holes are called the minority carrier.

The n-type and p-type silicon layers have a common meeting point called the **p-n junction**. At a zone in the cell called the depletion point both the n-type and p-type layers attract each other. An external conductor is needed to complete the circuit for the flow of electricity to be possible.

In the tropical sun, which is intensive, a single crystal PV cell of 100 cm^2 produces 1.5 watts of power at 0.5 V and 3 A. The power output of any PV cell depends upon the intensity of the sun. It is advisable to use a device to control the panel in the direction of the sun to harvest the maximum amount of radiant energy.

Solar electricity generation in Ghana

It has been recently reported in the Ghanaian media that parliament is seeking presidential assent to approve the procurement of more solar energy gadgets.

The Energy Commission has established solar villages in Volta, Eastern and the three Northern regions on a pilot basis. These solar projects are providing energy mainly for domestic and office use.

Solar heaters

Solar energy is utilised in hospitals and educational institutions to heat water. Since solar energy is abundant in the tropics and in free supply, its use is economical. Solar energy is environmentally friendly.

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Table 1.42 Solar electricity generated in Ghana

Solar system	Installed capacity in kilowatts	Generation/ Gigawatt-hour
rural solar home system	450	0.70–0. 90
urban solar home system	20	0.005–0.06
systems for school	15	0.01–0.10
systems for lighting health centres	6	0.01–0.10
vaccine refrigeration	42	0.08–0.09
solar water pumps	120	0.24–0.25
telecommunications	100	0.10–0.20
battery charging stations	10	0.01–0.10
grid connected systems	60	0.10–0.12
solar street lights	30	0.04–0.06

Source: Energy Commission, Ghana, July 2006.

ACTIVITY 1 Construction of a solar heater

1 Construct an aluminium box of dimensions 100 cm × 60 cm × 80 cm with the top and front view open as shown in Figure 1.145.

2 Paint the inside black to act as an anti-reflective zone and leave it to dry.

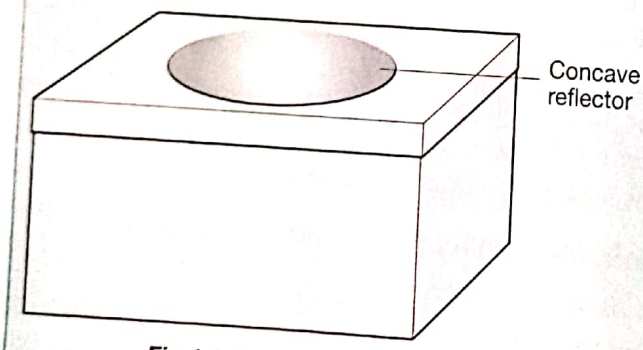


Fig 1.145 An aluminium box with the inside painted black.

3 Use a shiny metal to mould a concave cylindrical reflector and solder so it is fixed at the back of the box to reflect the solar energy to a focal point and to increase heat in the box.

4 Place a bowl of water in the solar box in the sun and record your observations in Table 1.43.

5 Plot a graph of the change in temperature with time.
- **a)** What was the highest temperature recorded?
- **b)** Can the heater be used to boil water?
- **c)** What can be done to improve the heat generated in the box?

Table 1.43

Volume of water	Initial temperature °C	Temperature after every 30 minutes					
		1st	2nd	3rd	4th	5th	6th

Solar drier

ACTIVITY 2 Design and construct a solar drier

1 Materials needed are plywood, a transparent polythene bag, nails and black paint. Design and construct a container as follows (Figure 1.46):

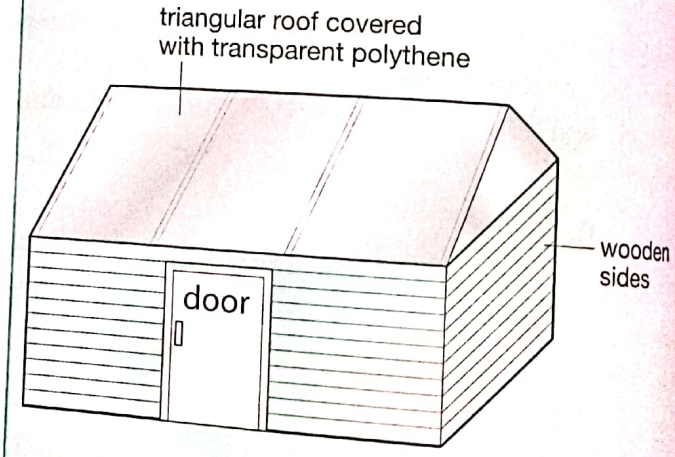


Fig 1.146

- **a)** Paint the inside of the box black to serve as an anti-reflective zone.
- **b)** Fix a concave reflector at the back of the triangular box to focus solar rays into the box.
- **c)** Place the box in the sun and leave it to dry.

2 Spread pepper and sliced okro or grains of maize on a platform in the box and record the rate at which it dries grains and fruits.

3 Design a device that can help to turn the materials being dried after every hour.

4 *Work in groups* to discuss what should be done to enable the solar drier to be used on a large scale for the cocoa industry?

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Applications of solar energy

Solar energy has been used traditionally in Ghana and elsewhere to dry and preserve fishes, pepper, cocoa beans, coffee, grains and seeds. Solar energy is used to dry clothes and to disinfect washed cooking utensils.

Solar energy is used in coastal towns to evaporate water from pools of sea water in order to obtain salt. Such a process is widely used by the Panbros Company in Dansoman, and other salt manufacturing industries are using solar energy to produce salt in Elmina and Ada.

Solar energy is widely used in agriculture to process and preserve a wide range of food, including 'Kokonte' and 'Tapioka' to season timber products.

Fishermen use solar energy to dry their mended nets and to dry fishes. Brick layers depend on solar energy to dry bricks for construction purposes.

Similarly, local potteries utilise solar energy to dry their baked pots and earthenwares.

Solar energy is a renewable energy and therefore highly dependable as a source of energy. It is environmentally friendly and available in all geographical regions in Ghana throughout the year.

Solar energy could be utilised to produce low cost electricity. It is an energy that promotes convectional rainfall in Ghana and other tropical countries. The infrared component of solar rays produces vitamin D in humans and is widely used in photosynthesis to optimise food production.

In our homes transparent louvres are used to allow solar radiant energy to pass into rooms to kill some germs.

In our schools solar energy improves the vision of students to facilitate reading and writing. Science students need solar energy for some experiments on photosynthesis and light.

Preservation and conservation of food are rendered cheaper when solar energy, which is basically free, is used. In agroforestry the treatment of wood is facilitated by the use of solar energy.

ACTIVITY 3 Investigating the uses of solar energy

Design a questionnaire to find out about the uses of solar energy in the following activities:

- laundry
- conservation of fruits and vegetables
- processing of food, e.g. 'Kokonte', 'Tapioke'
- boiling.

PROJECT 1 Making a solar heater and dryer

Design and construct a solar heater and drier specifically designed to boil eggs and to dry cocoa beans.

Self check

1 Explain why solar energy is described as environmentally friendly and dependable.

2 How is solar energy utilised in the following industries:
   a) fishing
   b) cocoa industry
   c) salt industry
   d) construction of houses.

3 Write an article advising the government on the need for a policy on the utilisation of solar energy for national development.

4 What factors account for the wide use of solar energy in Ghana?

5 Describe how solar driers are built and give five examples of the use of solar driers in Ghana.

6 What role does solar energy play in food production in Ghana?

7 Draw and label the parts of solar panels and describe how they are used to generate electricity.

8 What role does solar energy play in convectional rainfall?

9 'Solar energy is the backbone for the cocoa industry.' What is your stand on such a statement?

10 List any four factors that can optimise energy production in solar heaters.

11 Write an essay to show how solar energy can be used to meet the energy needs of the small communities in Ghana.

12 What are the disadvantages of solar energy?

13 In what ways can solar energy be stored for use?

14 What role do photons play in energy conservation by solar cells?

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3 Photosynthesis

Learning objectives

After studying this unit, you should be able to:

1 describe the process and conditions of photosynthesis
2 explain the process of the transformation of energy that occurs during photosynthesis.

Background information

Living things take food into their bodies for healthy growth and development, and to obtain energy for life activities. The energy in food comes originally from sunlight. Organisms which contain chlorophyll (e.g. green plants) use the energy in sunlight to make food in a chemical process known as **photosynthesis**. These organisms are described as **autotrophic** (self-feeders) because they make and use their own food. They are also described as **holophytic** because they use light energy for the synthesis of food.

Photosynthesis in flowering plants

Photosynthesis is the process by which simple inorganic substances, water and carbon dioxide are combined in the presence of sunlight and chlorophyll to form complex organic food substances such as glucose. Oxygen is given out as a by-product.

The process of photosynthesis is summarised in a balanced chemical equation:

$$6H_2O + 6CO_2 \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6 + 6O_2$$

water; carbon dioxide; glucose; oxygen

The green (foliage) leaves and the green stems of herbaceous plants, shrubs and trees are the organs in which photosynthesis occurs and glucose is produced. The glucose is converted into insoluble starch (a chain of glucose units) for storage. Other organic food substances – proteins, fats and oils (lipids) – are built from the sugar by chemical combination with other substances. To produce proteins, plants need elements, such as nitrogen and phosphorus. These are obtained from mineral salts absorbed from the soil.

Evidence for photosynthesis in a green leaf is the presence of starch in it. Starch is a large molecule found in certain food substances.

ACTIVITY 1 Testing for starch in a green leaf

Caution: Alcohol is highly flammable.

1 Pour a quantity of water into a beaker and heat it until it boils.
2 Pluck a green leaf from a flowering plant that has been in the light for 3–6 hours.
3 Using forceps, hold the leaf in the boiling water for 3 minutes. (This will kill the leaf cells, stop all chemical reactions in the cells and enable alcohol and iodine solution to penetrate the leaf tissues easily.)
4 Half fill a test tube with 70 per cent ethanol.
5 Using forceps again, place the leaf in the ethanol.
6 Remove the heat from the beaker of boiling water. Place the test tube containing ethanol and green leaf in the boiling water bath for 5 minutes. The ethanol will boil and dissolve out the chlorophyll. Record your observations about the colours of the leaf and of the alcohol after the boiling as well as the texture of the leaf.

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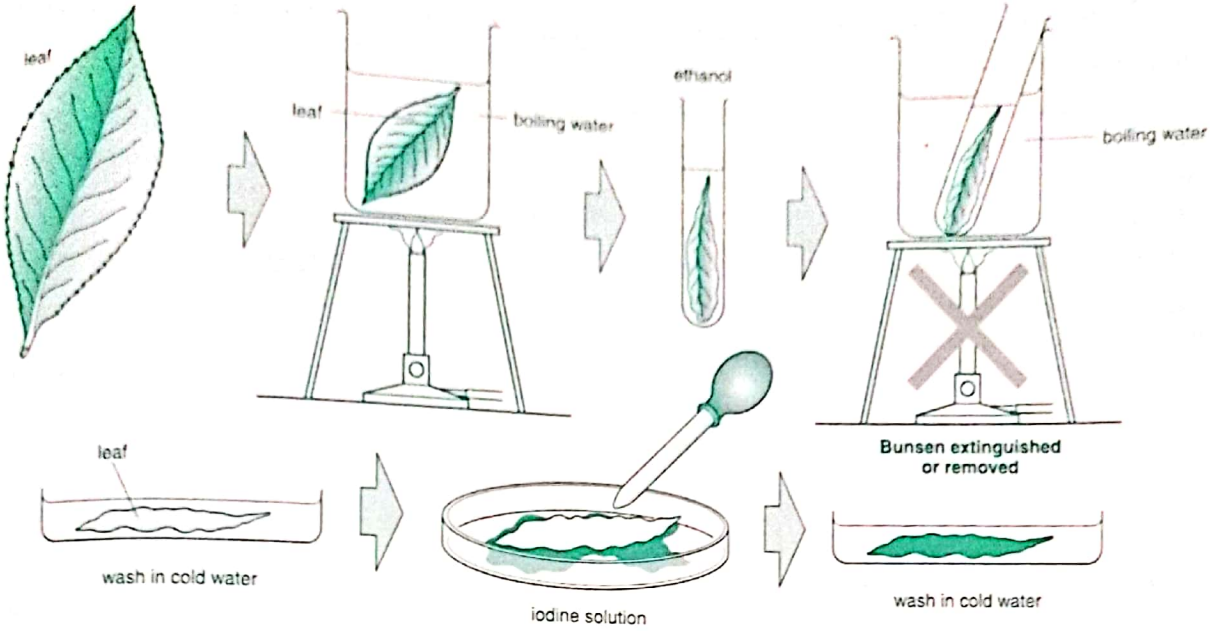


Fig 1.147 Testing for starch in a green leaf.

7 Why should you not heat the test tube containing alcohol and the leaf directly with the Bunsen flame? What is the role of the alcohol?

8 Use forceps to remove the leaf from the alcohol and wash it with cold water.

9 Dip the leaf in boiling water for 3 seconds to soften it.

10 Place the leaf on a white tile or in a Petri dish and add a few drops of iodine solution. A blue-black colour indicates the presence of starch. Record your observation (Figure 1.147).

11 Explain your observations.

12 State the process by which the food substance is formed.

ACTIVITY 2 Investigating the release of oxygen during photosynthesis

1 Fill a beaker with water and place some pond weed (e.g. *Elodea*, *Ceratophyllum* or *Spirogyra*) in the water. (A small amount of sodium hydrogencarbonate may be added to the water in the beaker to ensure an adequate supply of carbon dioxide.)

2 Invert a funnel over the weed and let it rest on supports, e.g. stones or lumps of plasticine. The stem of the funnel should be about 3 cm below the water surface. Why should the funnel rest on supports?

3 Fill a test tube to the brim with water. Cover its mouth tightly with your thumb to avoid air bubbles entering the tube. Invert it and place the covered mouth below the water surface and remove your thumb. Why should air bubbles be excluded from the test tube?

4 Place the mouth of the test tube over the stem of the funnel and lower the tube gently until it rests on the funnel.

5 Place the apparatus in bright light.

6 Set up a control experiment in the same way as in Figure 1.148 but without any pond weed under the funnel. Observe the two together for about 2 hours. What do you see happen inside each funnel and test tube?

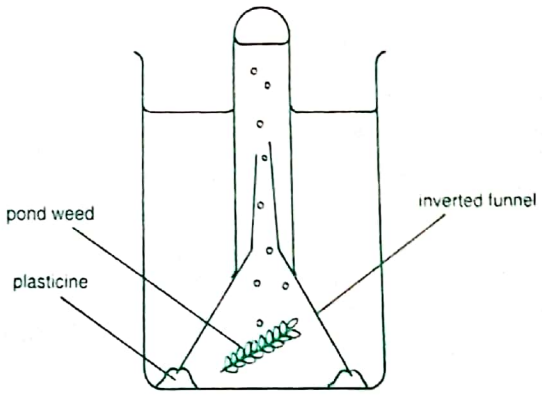


Fig 1.148 Release of oxygen by pond weed during photosynthesis.

7 When the test tube is about half full of gas, carefully lift it from the funnel, cover the open end with your thumb again and lift it from the water.

8 Invert the test tube, still keeping your thumb tightly over its mouth. Remove your thumb and quickly insert a glowing splint into the test tube. What happens to the glowing splint? Explain your observations.

9 What conclusion can you draw from your observations?

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Conditions necessary for photosynthesis

The next three activities investigate the necessity for carbon dioxide, light and chlorophyll for photosynthesis. It is important to **destarch** the leaves before carrying out these activities, since the starch which will be formed is what is being tested for. To destarch leaves, keep a potted plant in darkness continuously for about 2 days. A light proof cupboard is suitable for this. Test for the absence of starch in some of the leaves.

ACTIVITY 3 Investigating the need for carbon dioxide for photosynthesis

1 Destarch the leaves of a potted plant, e.g. cowpea or balsam.

2 Pluck a leaf from the plant and test it for starch. Is there any starch in the leaf?

3 Enclose one leaf in a conical flask labelled A, containing soda lime, and another leaf in another conical flask labelled B, without soda lime. Pass the leaf stalk through a split cork which has been greased to keep the flask air tight (Figure 1.149).

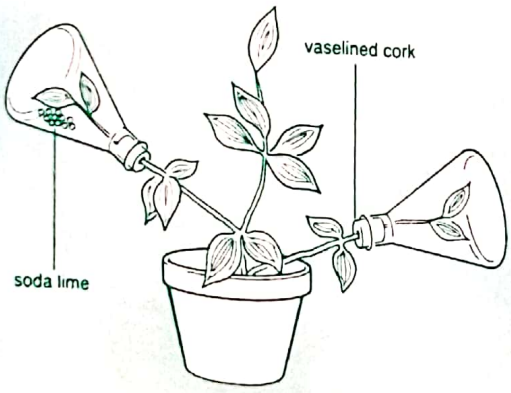


Fig 1.149 The necessity of carbon dioxide for photosynthesis.

4 What is the role of the soda lime in flask A? Why should the flasks be air tight?

5 Support each flask with a clamp. Place the plant in sunlight for about 3 hours. Remove the leaves from the flasks and test each for starch. Record your observation in each case.

6 *Work in groups* to discuss and explain the results.

7 Which leaf serves as the control? Explain this. What do you conclude from your observations?

ACTIVITY 4 Investigating the necessity of light for photosynthesis

1 Destarch the green leaves of a plant.

2 Cut a shape, such as a cross or star, from a piece of aluminium foil, cardboard or black paper and cover one of the leaves with it (Figure 1.150).

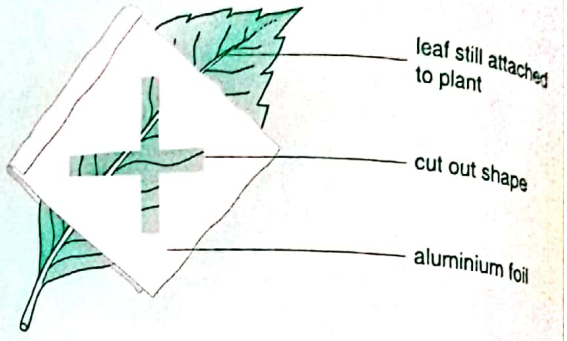


Fig 1.150 The necessity of light for photosynthesis.

3 Place the plant in sunlight for about 3 hours.

4 Remove the cover and test the leaf for starch. Compare the colours of the exposed part of the leaf and covered parts of the leaf.

5 *Work in groups* to discuss and explain your observation.

6 Which part of the leaf serves as the control? What do you learn from this experiment?

ACTIVITY 5 Investigating the necessity of chlorophyll for photosynthesis

1 Destarch a potted plant with variegated leaves (green and other colours), e.g. ice plant (*Breynia* sp.) or cemetery plant (*Croton* sp.).

2 Test a leaf to check that it is destarched. If there is still starch present, place the plant in the dark for another 24 hours (Figure 1.151).

3 Place the plant in sunlight for about 3 hours.

4 Draw one variegated leaf to show the pattern of green and non-green areas.

5 a) Test the leaf you have drawn for starch.
b) What do you observe?
c) Explain your observation.

6 What do you learn from this experiment?

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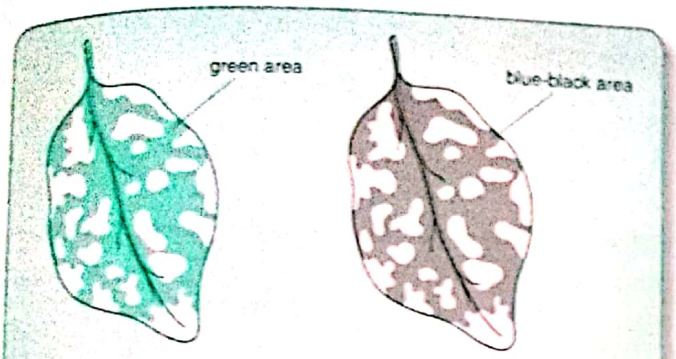


Fig 1.151 The necessity of chlorophyll for photosynthesis.

When a variegated leaf is tested for starch, the green parts (containing chlorophyll) turn blue-black in colour while the non-green parts (lacking chlorophyll) are merely stained with the colour of iodine solution (orange-brown).

Energy conversion during photsynthesis

In photosynthesis energy form sunlight is captured by organisms containing chlorophyll and converted into chemical energy. The organisms use the chemical energy produced to fix carbon dioxide into the high-energy products of photosynthesis, i.e. sucrose, glucose and starch. The energy conversion can be represented by the following equation:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{light energy}}{\text{photons}} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

Self check

For questions 1 to 8, choose the letter that refers to the correct option.

1 The energy used by living things to carry out life activities ultimately comes from:
A green plants **B** animals
C food **D** sun

2 Which of the following substances is one of the raw materials for photosynthesis?
A glucose **B** carbon dioxide
C oxygen **D** chlorophyll

3 Photosynthesis can only occur in the presence of:
A water, carbon dioxide and chlorophyll
B water, oxygen and chlorophyll
C carbon dioxide, chlorophyll and sunlight
D chlorophyll, oxygen and sunlight

4 The evidence that photosynthesis has taken place in a green leaf is the presence of:
A proteins **B** glucose
C starch **D** fats and oils

5 Which of the following solutions or chemicals is suitable for removing chlorophyll in a green leaf?
A methylated spirit **B** iodine solution
C Benedict's solution **D** Milton's reagent

6 Which of the following requirements is not essential for photosynthesis to take place in a plant?
A pressure of water **B** chlorophyll
C food reserve **D** carbon dioxide

7 Green plants perform all the following functions except:
A providing food for all primary consumers
B breaking down complex organic matter into simpler substances
C producing oxygen to replenish the atmosphere
D using carbon dioxide and water to build complex organic substances

8 Green plants store chemical energy mainly in the form of:
A carbohydrates **B** fats
C proteins **D** vitamins

9 a) How would you destarch a potted plant?
b) Describe how you would test a leaf for the presence of starch.
c) How would you show that chlorophyll is necessary for photosynthesis?

10 Name:
a) the raw materials for photosynthesis.
b) the conditions necessary for photosynthesis.

11 a) Summarise the process of photosynthesis in the form of a word equation.
b) State the uses of the products of photosynthesis.

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4 Electronics

Learning objectives

After studying this unit, you should be able to:

1 observe the behaviour of discrete electronic components in a d.c. and a.c. electronic circuit.

Background information

Components such as light emitting diodes, capacitors and inductors behave differently when powered by direct current than when alternating current drives current through them. In this unit we shall explore some of their behaviours and record them.

An electronic circuit is the circuit in which there are components, such as the source of energy (battery, cell or mains), switch or key, resistor and diode or light emitting diode that uses, transforms or controls electricity.

There are basic electronic components in an electronic circuit (Figure 1.152) which beginners need to know about. These include:

- conductors (wires)
- resistors
- diodes
- light emitting diodes (LEDs)
- capacitors
- inductors.



Fig 1.152 **(a)** Resistors **(b)** Diode **(c)** Light emitting diodes **(d)** Capacitors.

ACTIVITY 1 Identifying the basic components of an electronic circuit

Complete Table 1.44 by drawing the symbols for each component in an electronic circuit.

Table 1.44 Symbols of electronic circuit components

Component	Symbol in an electronic circuit
resistor	or
diode	
LED	
capacitor	
discharged capacitor	

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Components in d.c and a.c. electronic circuits

Resistor

This is a device which resists or retards the normal flow of current through a specific component in the electronic circuit or a sub-system in the circuit. Resistance to the flow of current by resistors is measured in ohms (Ω).

Carbon composition resistors are used which have capacities defined by colour codes as shown in Table 1.45. The colours represent a value of resistance. In each resistor there are four bands of colours.

Table 1.45 Values of resistance

Colour	Value
black	0
brown	1
red	2
orange	3
yellow	4
green	5
blue	6
purple	7
grey	8
white	9

ACTIVITY 2 Investigating the value of an electronic resistor

Materials required are different types of electronic resistors.

1 Use Table 1.45 to find the value of the resistance of different resistors collected.

Note: The first colour band on the left gives the value of the first digit, the second colour the value of the second digit and the third, the number of zeros. The fourth colour determines the precision of the resistance of the resistor.

2 State the function of an electronic resistor in an electronic circuit.

Diode

A diode is a device which permits the flow of current in one direction only. Diodes are made up of semiconductors. Semiconductors are made from silicon or germanium.

A diode has two parts: the n-type which is negative and the p-type which is positive (Figure 1.153). The n-type part is often called the majority carrier and the p-type part is deficient in electrons and is called the minority carrier.

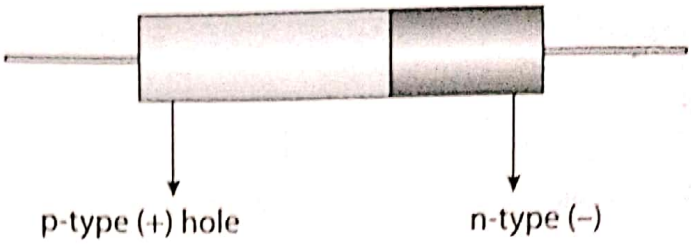


Fig 1.153 Diode.

The p-type (+) part which is deficient in electrons shows a vacancy and is called a hole. Hence, the hole also denotes a positive charge.

Since there is a hole or deficiency in the p-type (region) electrons flow to fill the hole in the p-type terminal of the battery. If the position is reversed it is referred to as **reverse bias** and under reverse conditions no current flows.

A special type of diode called a light emitting diode glows when a current passes through it.

Light emitting diode (LED)

The light emitting diode, also called LED, is a semiconductor which converts electrical energy into light (Figure 1.154).

A LED has low resistance and can work when connected to a maximum voltage of 1.5 V.

In a LED the longer terminal is the p-type (+) and the short terminal is the n-type (-) when connected to a direct current (d.c. source). The positive head is fixed on the positive terminal of the cell and the negative head is connected to the negative terminal of the cell. If the connection is confused or improperly done no light will be given off. When it gives light it is said to be **forward biased** and when it does not give light it is **reverse biased.**

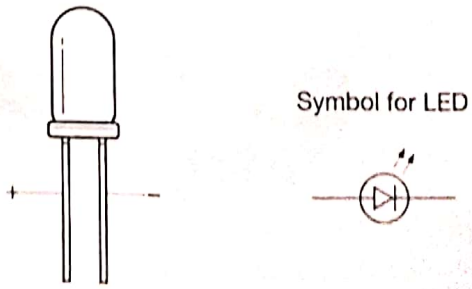


Fig 1.154 Light emitting diode.

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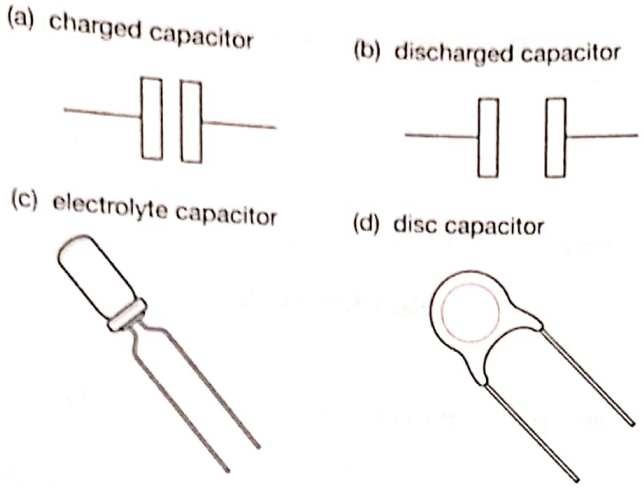


Fig 1.155 Capacitors.

Capacitor

Capacitors are devices that store electric charges. A capacitor is charged when a current flows through it in a one-way direction for a short time. A capacitor is said to be discharged when the current flows in the opposite direction. Capacitors consist of two metal plates which are separated by an insulator (Figure 1.155).

A capacitor has a property called capacitance which is measured in micro (μF) or pico farad. A farad is a measure of the capacity of a capacitor to store charges. Capacitors are always in sub-units of the farad.

Inductor

An inductor is a coil rolled into the form of a solenoid with a magnetic force field created in the coil. Inductors store electrical energy in the magnetic field. In this way, a sudden discharge of current in the current flow is prevented.

If the current in the magnetic field decreases, the coil collapses. To prevent the possible collapse the magnetic field induces (attracts) a voltage back into the inductor coil which sustains the current flow (Figure 1.156). The inductor may be air core, soft iron core, paper core or plastic core depending on the effect it should produce.

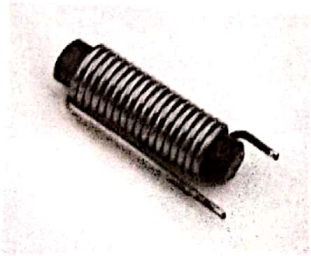


Fig 1.156 Induction coil.

Behaviour of components in d.c and a.c. electronic circuits

Light emitting diode (LED) in a d.c. circuit

ACTIVITY 3 Exploring the behaviour of a LED in a d.c. circuit

Materials needed are two 1.5 V cells, LED, wire, key and alligator clip.

1 Connect two 1.5 V cells with wires to the LED as shown in Figure 1.157.

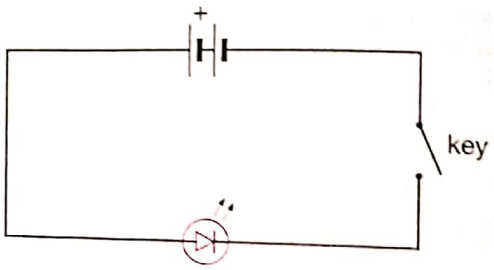


Fig 1.157 Light emitting diode in a d.c. circuit.

2 Switch on the circuit and record your observation.

3 Reverse the position of the LED by transferring the positive terminal to the negative terminal of the battery.

4 Close the circuit (switch on the key).

5 Record your observation.

6 Compare your observations and give reasons for what happened.

You might have observed that the LED produced light when the key was closed. Light energy was allowed to flow from the n-type to the p-type region. When the lead terminals were reversed no light was produced because the current was not allowed to flow.

In LEDs the current always flows from the majority carrier to the minority carrier. Remember that the LED is placed in an electronic circuit to control the direction of the flow of current.

Behaviour of resistors in a d.c. circuit

ACTIVITY 4 Investigating the behaviour of a resistor in a d.c. circuit

Materials needed are a 1000 Ω resistor, 100 000 Ω resistor, 9 V battery and a LED.

1 Connect the 9 V battery with flexible wire to a switch, resistor and LED as shown in Figure 1.158.

2 Switch on the key and observe what happens.

3 Replace the resistor with one of higher resistance, e.g. 100 000 Ω. Switch on the key.

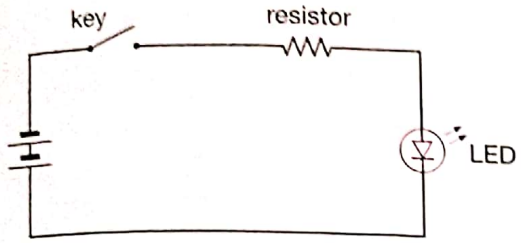


Fig 1.158 Resistor in a d.c. circuit.

4 Compare the brightness of the light from the LED. What do you infer from your observation?

You might have realised that the higher the value of the resistor, the greater the resistance to the flow of current and therefore the dimmer the light produced.

What would you do if you needed a brighter light?

How capacitors behave in a d.c circuit

Let us now explore how capacitors function in an electronic circuit.

ACTIVITY 5 Exploring the function of capacitors in a d.c circuit

1 Connect a 9 V battery, a switch and 100 µF (100 micro farad) capacitor in series to a LED as shown in Figure 1.159.

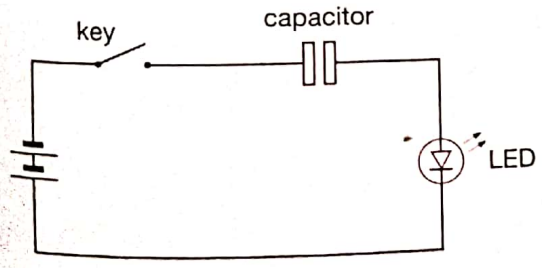


Fig 1.159 Capacitor in a d.c. circuit.

2 Close the circuit and record your observation.

3 Explain your observation.

ACTIVITY 6 Exploring the functions of a resistor

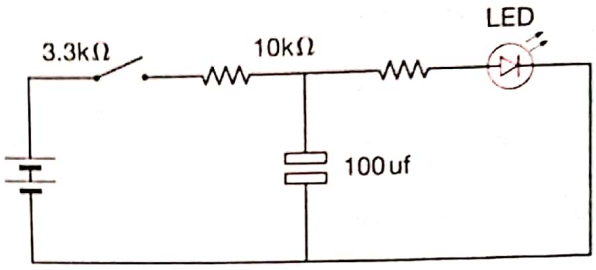


Fig 1.160 Functions of a resistor.

1 Connect a 3.3 kΩ resistor and a 10 kΩ resistor as shown in Figure 1.160.

2 Open and close the key many times.

3 Write down your observation.

4 Replace the 3.3 kΩ resistor with a 1.0 kΩ resistor. What do you observe this time?

5 Replace the 100 µf capacitor with a 10 µf capacitor. Switch on the current and record and compare your observations.

6 Vary the capacities of the resistors and capacitance and draw your conclusions.

You might have observed that without the resistor the LED lights up and dims rapidly. With the 3.3 kΩ resistor in series with the LED, the light comes on and dims slowly.

Are lighting systems on the streets or in speakers associated with fast or slow blinking of light?

There is a charge and discharge due to the presence of the capacitor. When the capacitance is low, e.g. 10 µf, the charging and discharging rates are faster and the LED lights up and dims very quickly.

PROJECT 1 Building an electronic circuit to produce light

1 Use capacitors, resistors and LEDs to build a circuit to produce light that attracts the attention of customers to a shop or to your house.

2 Explain how your circuit works.

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Inductors in electronic circuits

ACTIVITY 7 Investigating the function of an inductor in an electronic circuit

1 Use an insulated copper wire to make a coil of 50 turns.

2 Connect the coil prepared in series to a 1.5 V cell and a switch.

3 Connect a LED across the coil as in Figure 1.161.

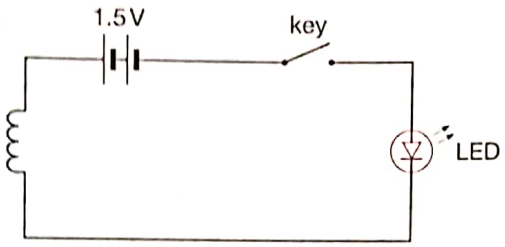


Fig 1.161 Inductor in an electronic circuit.

4 Switch on the key (close it) and record your observation.

5 Open the switch and record your observation.

Did you notice that when the circuit was closed the LED did not give off light, but when it was open there was a flash of light?

This happened because a large current was made to flow. This can destroy the LED if there is no resistor to control the flow of current into the LED. A lot of money is wasted if the LED needs to be replaced.

In the induction coil a tremendous amount of electrical energy is stored in the magnetic field created by the flow of current, but when the key is open the energy stored is released.

Behaviour of electronic components in an a.c. circuit

In an alternating current (a.c.) the direction of current flow reverses several times. This affects or influences the behaviour of the components of the circuit.

Let us investigate the behaviour of the components in a.c. circuits.

ACTIVITY 8 Exploring the behaviour of a LED in an a.c. circuit

Materials needed are a LED, 12 V a.c. source and connecting wire.

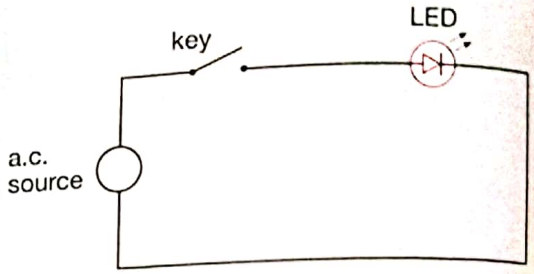


Fig 1.162 A light emitting diode in an a.c. circuit.

1 Connect a 12 V a.c. source in series to a switch and a LED with flexible connecting wires as shown in Figure 1.162.

2 Switch on the circuit and observe the LED.

3 Reverse the terminals of the LED.

4 Switch on the circuit and record your observations.

5 Comment on what you have observed.

Did you realise that the polarity of the LED does not affect the flow of current? The LED gives out light for any position of the terminals in an a.c. circuit.

ACTIVITY 9 Exploring the behaviour of capacitors in an a.c circuit

1 Connect a 12 V source to a capacitor as in Figure 1.163.

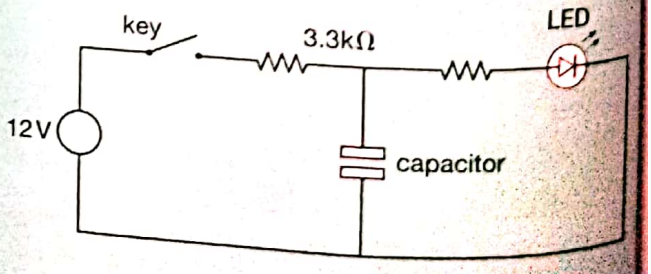


Fig 1.163 Capacitor in an a.c. circuit.

2 Switch on the key and record your observation.

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3 Open the circuit and compare your observation with when it was closed.

In this activity the blinking of the LED is not seen because the capacitor charges and discharges at great speed.

ACTIVITY 10 Investigating the behaviour of an inductor in an a.c. circuit

1 Connect a 12 V a.c. source as shown in Figure 1.164.

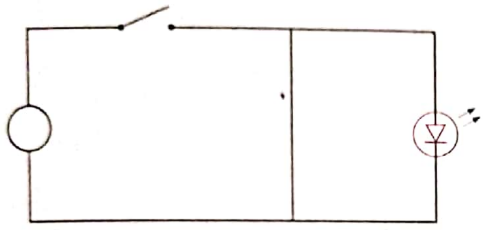


Fig 1.164 Inductor in an a.c. circuit.

2 Switch on the key and record your observation.

3 Open the circuit and compare your observation with when it was closed.

In this a.c. circuit, unlike the d.c. circuit, there are no flashes. The LED produces a stable light because there is a rapid reversal of the stored energy in the induction coil.

Self check

1 Briefly describe the following components of an electronic circuit:
   a) semiconductor
   b) diode
   c) resistor
   d) capacitor
   e) inductor.

2 Compare the difference in behaviour between a LED in a d.c. circuit and an a.c. circuit.

3 How do you determine the value of resistance of an electronic resistor?

4 How is an electronic resistor different from a diode?

5 What is the main function of a capacitor in an electronic circuit?

6 Why is it important to introduce a resistor across a capacitor and a LED?

7 List any three applications of electronic LEDs that you have observed in your community.

8 Distinguish between an electronic circuit and an electrical circuit.

9 **a)** Describe how you will construct an inductor with an insulated flexible wire and a stick.
   b) Compare the effects of the following inductors on the behaviour of a LED.
   (i) air core inductor
   (ii) soft iron core inductor
   (iii) paper core inductor.

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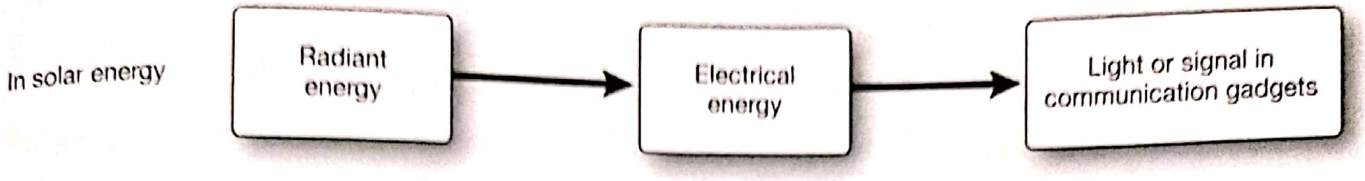


Fig 1.138 Conversion of solar energy.

The discovery of semiconductor substances, such as germanium and silicon, has led to the development of solar panels and solar cells which convert solar energy into electrical energy in order to power solar gadgets (Figure 1.138). In Ghana solar panels are widely used in solar villages in Eastern, Volta and the three Northern regions.

Fossil fuel

Fossil fuel is the deposition of organic matter in the soil over millions of years to produce crude oil.

Firewood, charcoal and wastes from fruits and seeds have been a traditional source of energy for cooking and baking in many homes. This is called **biomass**. Technology has led to the mining and fractional distillation of crude oil which has broadened the petrochemical industries (Figure 1.139).

Biomass is converted into biogas with digesters to produce biogas for domestic use (Figure 1.140).

Forms of energy

Potential energy

Potential energy is defined as the energy possessed by a body by virtue of its position relative to a reference point, such as the ground, or its position in a field of force. Potential energy may either be a gravitational potential energy or an elastic potential energy, e.g. found in shooting arrows from bows or springs.

Gravitational potential energy is determined by the mass of the body and acceleration due to the force of gravity reacting on the body.

$$\text{Potential energy} = \text{mass} \times \text{acceleration due to gravity} \times \text{height}$$

$$P = mgh$$

where m = mass, g = acceleration due to gravity and h = height from the object to the ground.

Elastic potential energy is defined by the product of the spring constant and the compression or extension of the elastic material, such as spring or elastic material.

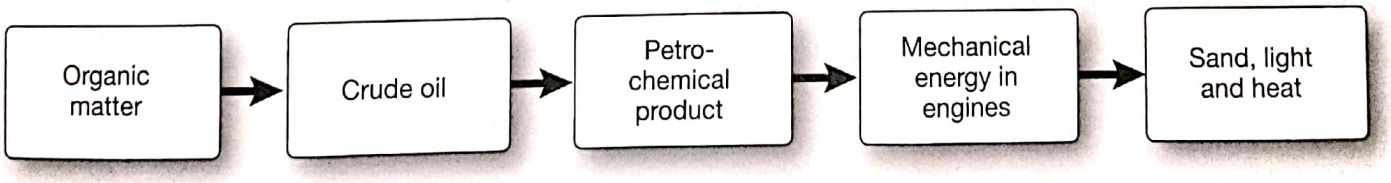


Fig 1.139 Energy transformations into crude oil and petrochemical products.

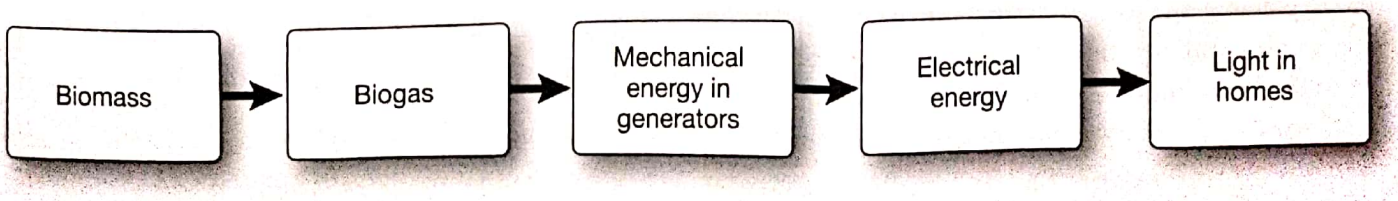


Fig 1.140 Energy transformations from biomass into light energy in homes.

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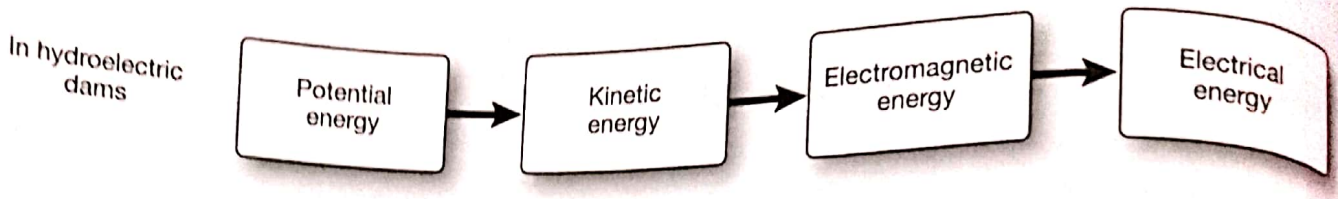


Fig 1.141 Energy transformations in hydroelectric dams.

Elastic potential energy = $\frac{1}{2}$ k × the extension or compression of the elastic material, where k is the elastic contant.

Kinetic energy

Potential energy can easily be converted into kinetic energy when, as a result of an external force, the object or system is set in motion.

$$KE = \frac{1}{2}mv^2$$

where m = mass and v = velocity of the object in motion.

Water stored behind a dam has a high potential energy that is released to flow to propel turbines with dynamos to convert mechanical energy into electrical energy (Figure 1.141).

Electrical energy

A massive flow of electrons generated as a result of mechanical or chemical reactions generates electricity to power domestic as well as industrial appliances in homes and workplaces, respectively.

Cellular respiration

Chemical energy is liberated from glucose during organic cellular respiration in plants and animals. This is the source of energy for plants and animals and is referred to as **tissue respiration**.

Other forms of energy

In Ghana thermal energy from the burning of crude oil or its by-products is used to generate electric energy to supplement the hydroelectricity generated from the Akosombo and Kpong dams, and in the near future from the Bui dam, which is under construction.

Electrostatic energy is produced by the collision of rain bearing clouds, releasing a flow of charged particles through the atmosphere which harm, in most cases, tall buildings and trees when the particles flow through them.

Renewable forms of energy, such as geothermal, sea wave related, wind and solar energy are being considered by governments for national development.

Conversion of energy

Energy can be transformed from one form into another. The flow charts above indicate how energy conversion occurs.

ACTIVITY 1 Energy transformations

1 *Work in groups* to represent the following energy transformations using drawings and flow charts:

a) solar energy to chemical energy in photsynthesis

b) electrical energy to light energy in a bulb

c) release of chemical energy from glucose during cellular respiration.

Conservation of energy and efficiency of energy conversion

Principle of conservation of energy

The **principle of energy conservation** states that energy is neither created nor destroyed but is transformed from one form into another.

Energy in any process is neither produced nor used up. In processes:

- no new energy is created
- the total existing energy is not destroyed
- energy is changed from one form into another

Efficiency of energy

The efficiency of energy is the ratio between the useful energy obtained to the total energy transformed and is expressed in terms of percentage.

Mathematically, the efficiency of an energy change is given as:

$$\text{Efficiency (E)} = \frac{\text{useful energy obtained}}{\text{total energy transformed}} \times 100\%$$

$$\text{or} \quad = \frac{\text{energy output}}{\text{energy input}} \times 100\%$$

$$\text{or} \quad = \frac{\text{work output}}{\text{work input}} \times 100\%$$

Efficiency is always less than 100% because part of the energy is used to overcome friction of parts of the machine.

Self check

1 Explain the following terms:
   a) voltaic cell
   b) solar panel
   c) mechanical energy.

2 Distinguish between energy from biomass and energy from a radiant source.

3 Draw a flow chart to demonstrate the energy transformations that happens in:
   a) voltaic cell
   b) solar cell
   c) biogas for cooking.

4 Compare potential energy and kinetic energy and outline the similarities and differences between them.

5 Explain why crude oil as a fossil fuel can be linked to biomass as a source of energy.

6 Use a flow chart to demonstrate how the potential energy of water behind a dam is transformed into electrical energy for use in homes.

7 Explain how crude oil is converted into thermal energy at Aboadze in the Western region of Ghana.

8 Describe how energy is produced from cell respiration.

9 How is elastic energy transformed into kinetic energy in a bow and arrow?

10 Why is energy said to be conserved? Use flow charts to show the energy of transformation in photosynthesis and tissue respiration.

11 Explain the term 'efficiency of energy'.

12 Why is the efficiency of energy always less than 100 per cent in mechanical devices?

Richmond

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2 Solar energy

Learning objectives

After studying this unit, you should be able to:

1 identify the uses of solar energy
2 document the use of solar energy in daily activities
3 model a solar heater and dryer.

Uses of solar energy

Our parents have depended on the radiant energy from the sun for preservation and conservation of grains, seeds and vegetables for many years. Sunbaked brick has been a useful architectural material for the construction of many buildings in many villages.

Plants through photosynthesis manufacture glucose which serves as a store of energy for both plants and some animals. In recent years the discovery of semiconductors made from silicon and germanium has led to the construction of solar panels to trap photons from solar energy and convert them into electrical energy to power homes, heat water and provide energy for electronic devices, such as digitised clocks and solar lamps (Figure 1.142).

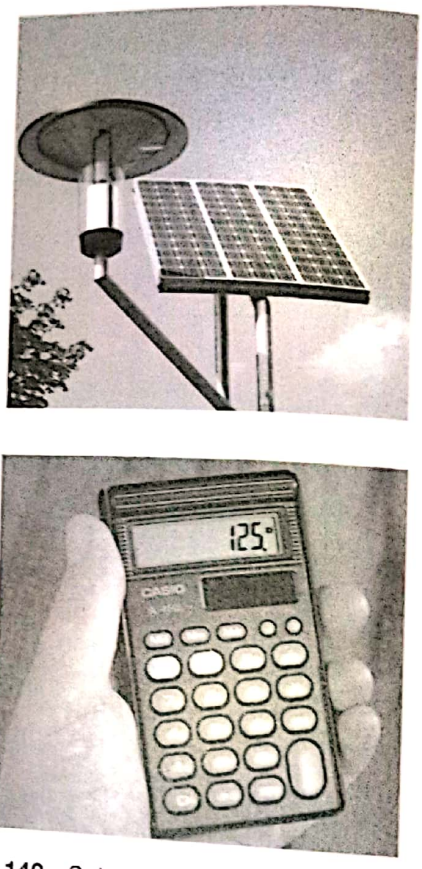


Fig 1.142 Solar energy devices **(a)** solar lamp **(b)** electronic calculator powered by solar panel.

Generation of electricity from solar panel/solar cells

Solar panels

A solar panel is a device which collects and transforms solar energy into electricity.

The device has the following features and respective functions:

- photovoltaic (PV) structure also referred to as the PV module
- solar thermal collector – traps heat from the solar radiation called photons
- solar hot water panels – use radiant energy to heat water for homes, institutions and hospitals
- solar lamps – have solar cells to store solar energy to provide light in lamps for homes.

The PV module is a collection of solar cells also known as photovoltaic cells (Figure 1.143). The cells are arranged into panels which are parallel to each other to convert photons into electrical energy.

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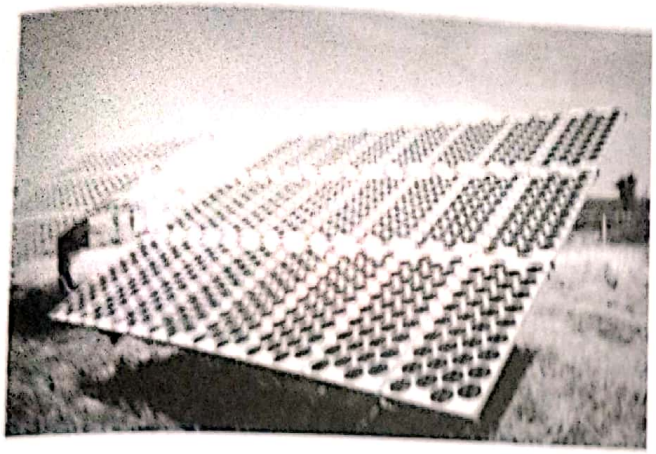


Fig 1.143 Photovoltaic module.

In the PV module a number of cells are mechanically assembled and wired to form a compact unit for installation. A solar panel has the following components:

- inverter
- batteries
- wiring.

A solar panel is used to produce electricity to pump water for irrigation, to charge photovoltaic cells, to produce light and to power some communication gadgets.

Solar cells

In this type of cell solar energy is converted into electrical energy and stored to produce an electromotive force which sets myriads of electrons into motion.

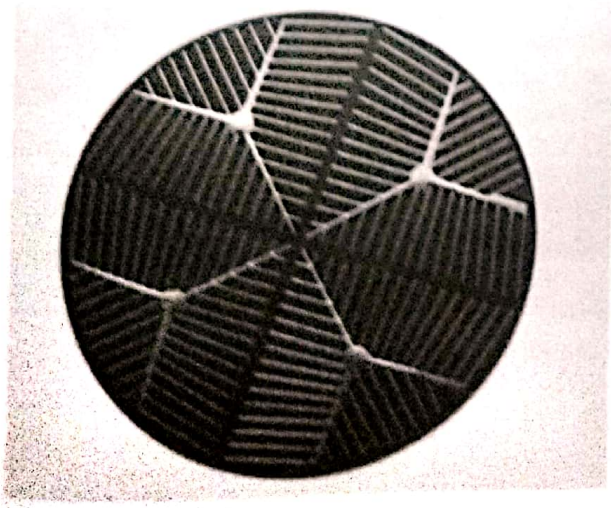


Fig 1.144 Solar cell.

The components of a solar cell are (*Figure 1.144*):

- encapsulate
- contact grid
- anti-reflective coating (AR coating)
- n-type silicon (negative)
- p-type silicon (positive)
- back cover (often glass).

How solar cells work

When radiant energy (photons) enter the encapsulate they enter the entire reflective layer, which is dark in colour. The photons travel from the anti-reflective layer to the lower layer of the cell.

In the lower layer the photons strike the silicon surface, which is also called the contact grid. At this stage enormous numbers of electrons are mobilised to flow. In the n-type silicon layer the free electrons are called the majority carrier and the holes are called the minority carrier.

The n-type and p-type silicon layers have a common meeting point called the **p-n junction**. At a zone in the cell called the depletion point both the n-type and p-type layers attract each other. An external conductor is needed to complete the circuit for the flow of electricity to be possible.

In the tropical sun, which is intensive, a single crystal PV cell of 100 cm^2 produces 1.5 watts of power at 0.5 V and 3 A. The power output of any PV cell depends upon the intensity of the sun. It is advisable to use a device to control the panel in the direction of the sun to harvest the maximum amount of radiant energy.

Solar electricity generation in Ghana

It has been recently reported in the Ghanaian media that parliament is seeking presidential assent to approve the procurement of more solar energy gadgets.

The Energy Commission has established solar villages in Volta, Eastern and the three Northern regions on a pilot basis. These solar projects are providing energy mainly for domestic and office use.

Solar heaters

Solar energy is utilised in hospitals and educational institutions to heat water. Since solar energy is abundant in the tropics and in free supply, its use is economical. Solar energy is environmentally friendly.

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Table 1.42 Solar electricity generated in Ghana

Solar system	Installed capacity in kilowatts	Generation/ Gigawatt-hour
rural solar home system	450	0.70–0. 90
urban solar home system	20	0.005–0.06
systems for school	15	0.01–0.10
systems for lighting health centres	6	0.01–0.10
vaccine refrigeration	42	0.08–0.09
solar water pumps	120	0.24–0.25
telecommunications	100	0.10–0.20
battery charging stations	10	0.01–0.10
grid connected systems	60	0.10–0.12
solar street lights	30	0.04–0.06

Source: Energy Commission, Ghana, July 2006.

ACTIVITY 1 Construction of a solar heater

1 Construct an aluminium box of dimensions 100 cm × 60 cm × 80 cm with the top and front view open as shown in Figure 1.145.

2 Paint the inside black to act as an anti-reflective zone and leave it to dry.

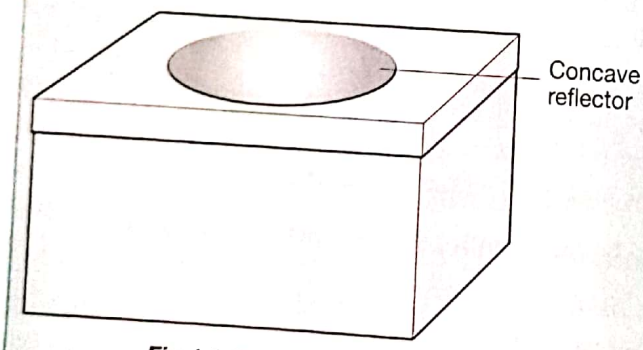


Fig 1.145 An aluminium box with the inside painted black.

3 Use a shiny metal to mould a concave cylindrical reflector and solder so it is fixed at the back of the box to reflect the solar energy to a focal point and to increase heat in the box.

4 Place a bowl of water in the solar box in the sun and record your observations in Table 1.43.

5 Plot a graph of the change in temperature with time.
- **a)** What was the highest temperature recorded?
- **b)** Can the heater be used to boil water?
- **c)** What can be done to improve the heat generated in the box?

Table 1.43

Volume of water	Initial temperature °C	Temperature after every 30 minutes					
		1st	2nd	3rd	4th	5th	6th

Solar drier

ACTIVITY 2 Design and construct a solar drier

1 Materials needed are plywood, a transparent polythene bag, nails and black paint. Design and construct a container as follows (Figure 1.46):

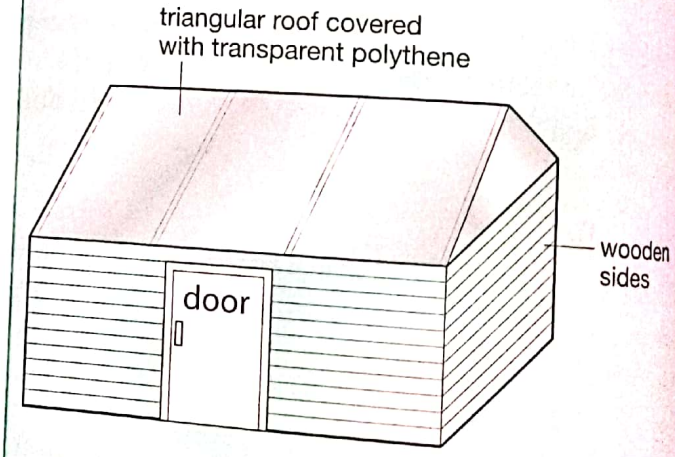


Fig 1.146

- **a)** Paint the inside of the box black to serve as an anti-reflective zone.
- **b)** Fix a concave reflector at the back of the triangular box to focus solar rays into the box.
- **c)** Place the box in the sun and leave it to dry.

2 Spread pepper and sliced okro or grains of maize on a platform in the box and record the rate at which it dries grains and fruits.

3 Design a device that can help to turn the materials being dried after every hour.

4 *Work in groups* to discuss what should be done to enable the solar drier to be used on a large scale for the cocoa industry?

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Applications of solar energy

Solar energy has been used traditionally in Ghana and elsewhere to dry and preserve fishes, pepper, cocoa beans, coffee, grains and seeds. Solar energy is used to dry clothes and to disinfect washed cooking utensils.

Solar energy is used in coastal towns to evaporate water from pools of sea water in order to obtain salt. Such a process is widely used by the Panbros Company in Dansoman, and other salt manufacturing industries are using solar energy to produce salt in Elmina and Ada.

Solar energy is widely used in agriculture to process and preserve a wide range of food, including 'Kokonte' and 'Tapioka' to season timber products.

Fishermen use solar energy to dry their mended nets and to dry fishes. Brick layers depend on solar energy to dry bricks for construction purposes.

Similarly, local potteries utilise solar energy to dry their baked pots and earthenwares.

Solar energy is a renewable energy and therefore highly dependable as a source of energy. It is environmentally friendly and available in all geographical regions in Ghana throughout the year.

Solar energy could be utilised to produce low cost electricity. It is an energy that promotes convectional rainfall in Ghana and other tropical countries. The infrared component of solar rays produces vitamin D in humans and is widely used in photosynthesis to optimise food production.

In our homes transparent louvres are used to allow solar radiant energy to pass into rooms to kill some germs.

In our schools solar energy improves the vision of students to facilitate reading and writing. Science students need solar energy for some experiments on photosynthesis and light.

Preservation and conservation of food are rendered cheaper when solar energy, which is basically free, is used. In agroforestry the treatment of wood is facilitated by the use of solar energy.

ACTIVITY 3 Investigating the uses of solar energy

Design a questionnaire to find out about the uses of solar energy in the following activities:

- laundry
- conservation of fruits and vegetables
- processing of food, e.g. 'Kokonte', 'Tapioke'
- boiling.

PROJECT 1 Making a solar heater and dryer

Design and construct a solar heater and drier specifically designed to boil eggs and to dry cocoa beans.

Self check

1 Explain why solar energy is described as environmentally friendly and dependable.

2 How is solar energy utilised in the following industries:
   a) fishing
   b) cocoa industry
   c) salt industry
   d) construction of houses.

3 Write an article advising the government on the need for a policy on the utilisation of solar energy for national development.

4 What factors account for the wide use of solar energy in Ghana?

5 Describe how solar driers are built and give five examples of the use of solar driers in Ghana.

6 What role does solar energy play in food production in Ghana?

7 Draw and label the parts of solar panels and describe how they are used to generate electricity.

8 What role does solar energy play in convectional rainfall?

9 'Solar energy is the backbone for the cocoa industry.' What is your stand on such a statement?

10 List any four factors that can optimise energy production in solar heaters.

11 Write an essay to show how solar energy can be used to meet the energy needs of the small communities in Ghana.

12 What are the disadvantages of solar energy?

13 In what ways can solar energy be stored for use?

14 What role do photons play in energy conservation by solar cells?

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3 Photosynthesis

Learning objectives

After studying this unit, you should be able to:

1 describe the process and conditions of photosynthesis
2 explain the process of the transformation of energy that occurs during photosynthesis.

Background information

Living things take food into their bodies for healthy growth and development, and to obtain energy for life activities. The energy in food comes originally from sunlight. Organisms which contain chlorophyll (e.g. green plants) use the energy in sunlight to make food in a chemical process known as **photosynthesis**. These organisms are described as **autotrophic** (self-feeders) because they make and use their own food. They are also described as **holophytic** because they use light energy for the synthesis of food.

Photosynthesis in flowering plants

Photosynthesis is the process by which simple inorganic substances, water and carbon dioxide are combined in the presence of sunlight and chlorophyll to form complex organic food substances such as glucose. Oxygen is given out as a by-product.

The process of photosynthesis is summarised in a balanced chemical equation:

$$6H_2O + 6CO_2 \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6 + 6O_2$$

water; carbon dioxide; glucose; oxygen

The green (foliage) leaves and the green stems of herbaceous plants, shrubs and trees are the organs in which photosynthesis occurs and glucose is produced. The glucose is converted into insoluble starch (a chain of glucose units) for storage. Other organic food substances – proteins, fats and oils (lipids) – are built from the sugar by chemical combination with other substances. To produce proteins, plants need elements, such as nitrogen and phosphorus. These are obtained from mineral salts absorbed from the soil.

Evidence for photosynthesis in a green leaf is the presence of starch in it. Starch is a large molecule found in certain food substances.

ACTIVITY 1 Testing for starch in a green leaf

Caution: Alcohol is highly flammable.

1 Pour a quantity of water into a beaker and heat it until it boils.
2 Pluck a green leaf from a flowering plant that has been in the light for 3–6 hours.
3 Using forceps, hold the leaf in the boiling water for 3 minutes. (This will kill the leaf cells, stop all chemical reactions in the cells and enable alcohol and iodine solution to penetrate the leaf tissues easily.)
4 Half fill a test tube with 70 per cent ethanol.
5 Using forceps again, place the leaf in the ethanol.
6 Remove the heat from the beaker of boiling water. Place the test tube containing ethanol and green leaf in the boiling water bath for 5 minutes. The ethanol will boil and dissolve out the chlorophyll. Record your observations about the colours of the leaf and of the alcohol after the boiling as well as the texture of the leaf.

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- **Aquatic habitats** – the sea (and the seashore), lakes, ponds, ditches, rivers, streams and irrigated farmland; inhabited by a wide variety of water-dwelling plants and animals.
- **Forest habitats** – tend to be dominated by birds and insects, but many mammals, reptiles and other invertebrates also inhabit the trunks and canopies of trees.
- **Population** – the term given to all the organisms of a single species living in a habitat. For example, a school compound (habitat) may contain a population of agama lizards.
- **Community** – all the populations of all the different species in a habitat. A community, together with all the non-living parts of a habitat (including climate, rainfall, etc.) make up an ecosystem.
- **Ecosystem** – a community and its environment. The term ecosystem is also used when describing large areas; for example, a tropical rain forest (biome), together with all the living organisms that inhabit it, can be referred to as an ecosystem.
- **Niche** – the space within an ecosystem occupied by an organism; largely dependent upon its way of life. Niches of different organisms quite often overlap within a habitat, resulting in interactions between the organisms. For example, lions and hyenas occupy similar niches on the savannah plains but they are able to live side by side due to different feeding habits.

Ecological factors

The environment of an organism includes all the living and non-living things that surround it. They all affect the organism in some way and are referred to as ecological factors. They can be divided into **abiotic** (non-living) and **biotic** (living) factors.

Abiotic factors

Abiotic factors are physical factors which affect living things and their environment. Some are climatic, e.g. rainfall, temperature and light intensity. Others, like altitude and slope of land, can be called physiographic factors. All abiotic factors can be measured.

Temperature

Temperature is an important climatic factor. Fluctuations in temperature have wide-ranging effects. Organic matter decays more rapidly in high temperatures. High temperatures speed up the growth of some organisms, e.g. the road. High temperature also has physical effects; for instance, it increases the rate of evaporation of water, causing the soil to dry out more rapidly and making it difficult to till the soil during the dry season. High temperatures also cause rivers and streams to dry up during the dry season, leading to problems with water supply. On the other hand, low temperatures generally slow down the growth and other activities of organisms, e.g. fruits ripen more slowly. In a particular habitat the temperature undergoes daily fluctuations and may also vary in different parts of the habitat. Temperature is measured with **thermometers**.

ACTIVITY 1 Studying temperature fluctuations in a tropical rain forest

1 Look at Figure 1.165, which shows temperature changes in a rain forest over a 24-hour period.

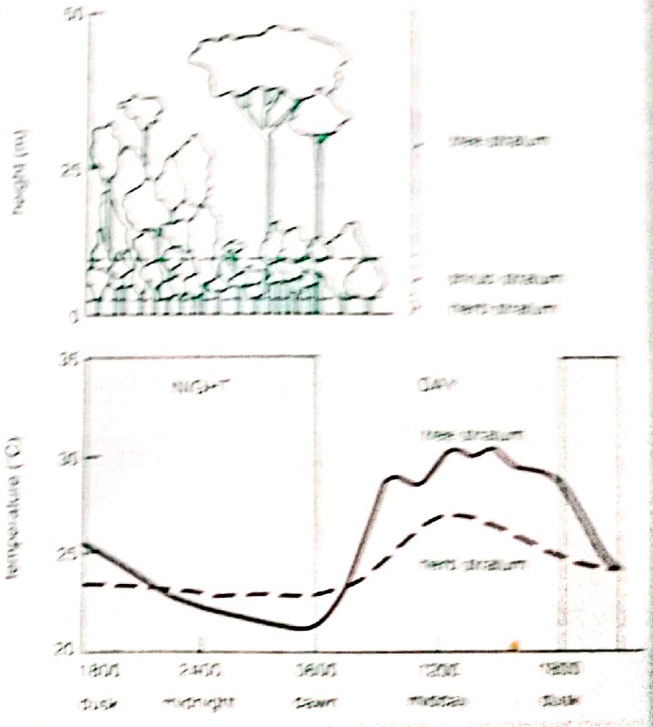


Fig 1.165 A graph showing the diurnal changes in temperature in a rain forest during a 24-hour period.

a) Why is the temperature in the herb stratum (layer) lower than the temperature in the tree stratum?

1 Ecosystems

Learning objectives

After studying this unit, you should be able to:

1 define the basic ecological terms
2 classify ecosystems and identify their components
3 describe the components of a food chain and food web and how they are interrelated.

Background information

Matter, though diverse, does interact to foster unity and harmony. In order to understand and appreciate such a phenomenon we need to carefully study, understand, promote and sustain the interaction of matter for our sustainable development.

In so doing we shall carefully study the ecosystems, the atmosphere and climate change and the movement that occurs in the Earth's crust. We shall also examine some diseases and how they are caused, spread and controlled.

Ecology is the study of the interrelationships between plants and animals (including humans) and their environment. Ecology is one of the branches of biology. Biologists who work in this field are called ecologists. Their work involves observations of the positive and negative effects of living things on their surroundings and vice versa.

A knowledge of ecology can be very useful in other subject areas, e.g. agriculture and community health. Farmers can use their knowledge of soil types and vegetation to decide on the best crops to grow in a particular area. In developing countries, like Ghana, farmers need a good knowledge of rainfall patterns, as a good harvest is dependent upon planting the crop at a time that will make the most of any rainfall. Good knowledge of the ecology of an area also helps people to make decisions about the exploitation of natural resources; for example, the felling of trees or the extraction of mineral ores from the ground.

Fundamental ecological concepts

Several important terms are used frequently by ecologists:

- **Species** – species can be defined as groups of potentially interbreeding natural populations which are reproductively isolated from other such groups.
- **Ecosphere** – in ecology the term ecosphere can refer to the global ecosystem of the planet (essentially the same as biosphere). An ecosphere is therefore a closed ecosystem, a fully self-contained, self-sustaining miniature world encased in a glass.
- **Biosphere** – that part of the Earth's surface and the atmosphere (land, sea and air) that is inhabited by living organisms. The biosphere can be divided into several biomes. A biome is a large, natural area with a particular climate. Africa has several such biomes, e.g. desert, tropical rain forest, savanna or grassland and swamps. Each biome can be further divided into zones. For example, a tropical rain forest has a ground zone and a canopy zone. Within each zone are numerous habitats.
- **Habitat** – the natural home of an organism. Often the organism has evolved special adaptations which enable it to live successfully in its habitat. The three major types of habitat are terrestrial (land), aquatic (water) and forest.
- **Terrestrial habitats** – farmland, parks, savanna, desert, rain forest, etc.; inhabited by a diverse variety of plants and animals.

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b) Describe how the temperature changes in (i) the tree stratum and (ii) the herb stratum over the 24-hour period.
c) What is the temperature difference between the two layers at (i) 2100 hours and (ii) 1200 hours?
d) During what period of time will the rate of photosynthesis be highest?

2 Cold-blooded animals cannot control their body temperature, so it varies according to the temperature of their surroundings. When might cold-blooded animals be most active? Give reasons for your answer.

Rainfall

Rainfall, another climatic factor, undergoes seasonal fluctuations. This is illustrated in Figure 1.166.

It shows that the year can be divided into wet and dry seasons. This affects both plant and animal populations, with many organisms having special adaptations for survival during the dry periods. Some species of African butterfly have different forms for wet and dry seasons. Some organisms which rely on water are able to aestivate during the dry season, i.e. they surround themselves with a protective covering and become inactive. During aestivation the animal uses little energy and lives on stored food materials. Many species of snail are able to survive the dry season in this way.

The amount of water available from rain determines the type of vegetation that will grow in a particular area. Fluctuations in rainfall directly affect the growth of vegetation, which alters the amount of food available to herbivores. This has an indirect effect on the whole food chain.

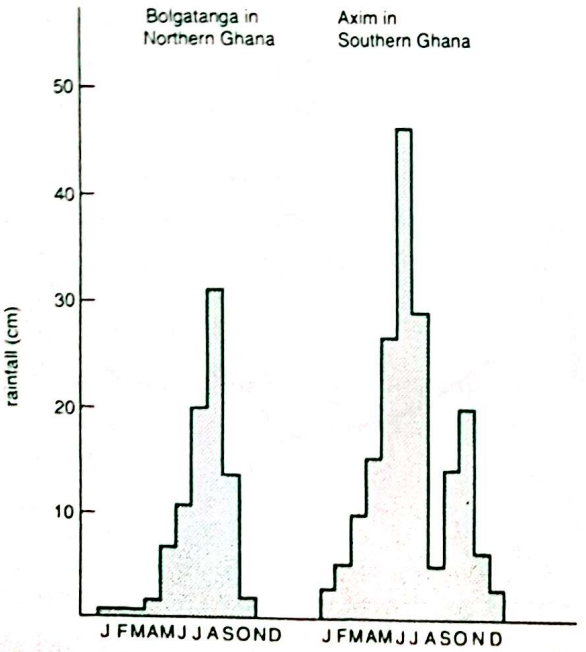


Fig 1.166 Monthly rainfall pattern for a one year period in Bolgatanga and Axim.

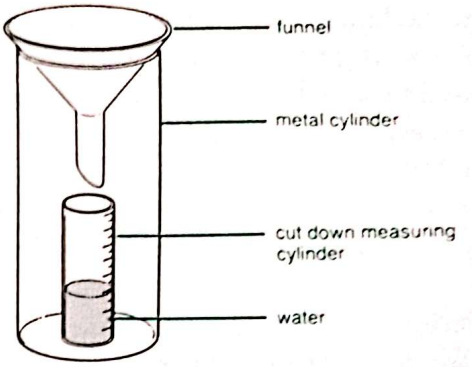


Fig 1.167 A rain gauge.

Rainfall is measured with a rain gauge (Figure 1.167). The metal cylinder is embedded in the ground in an open area where rain can fall directly into the funnel. Rain is channelled into the measuring cylinder and the contents of this can be measured and recorded at 24-hour intervals. The readings can be used to draw a bar chart similar to that in Figure 1.166.

Light

Light intensity affects green plants to a greater extent than animals, because green plants utilise sunlight in photosynthesis. Plants that live in shady places, such as the ground zone of a tropical rain forest, have evolved to survive in low light intensity. In aquatic habitats light intensity decreases with increasing depth of water which affects the distribution of plant species growing at different depths. The life cycles of some plants growing in temperate climates are controlled by seasonal variations in the number of daylight hours. Light intensity can be measured with a **photometer**. This is similar to the type of light meter used in conjunction with cameras.

Humidity

Relative humidity is a measure of the amount of water vapour in the atmosphere. Variation in this factor affects the distribution of organisms, particularly small invertebrates and higher plants. Fluctuations in relative humidity also affect the rate of water loss in animals and plants. An increase in humidity decreases the rate of water loss.

Wind

Many habitats are affected by the direction and strength of winds. Effective dispersal of some fruits and seeds are dependent on prevailing winds. Birds, insects and

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other flying animals are also affected by wind direction and velocity, both in everyday life and during their migration. Strong winds can cause soil erosion, damage trees and uproot smaller plants.

Altitude

Altitude refers to vertical height above sea level. Air pressure and oxygen levels decrease as altitude increases. Organisms living at high altitudes have adapted to cope with these conditions. Places such as Abetifi-Kwahu and Aburi, in the Eastern region of Ghana, also experience lower temperatures and stronger winds.

Depth of water

Organisms living in water need to be able to cope with changes in pressure, light intensity, oxygen concentration and temperature, and in sea water, salinity (saltiness). Pressure increases with depth, while oxygen levels, temperature and light intensity decrease with depth.

Hydrogen ion concentration

The concentration of hydrogen ions in water (in aquatic habitats or in soil), determines the acidity or alkalinity. This is usually referred to as pH. Variation in pH of soil greatly affects the distribution of plants. Some plants thrive in acid soils, while others grow better in alkaline soils.

Salinity

Salinity is the saltiness or dissolved salt content of a body of water. It is therefore a measure of how much salt is dissolved in water. The saltier the water, the greater its salinity.

Biotic factors

These factors are concerned with the way in which living organisms interact with one another in a habitat. These interactions may have both useful and harmful results. Some examples of useful biotic factors are:

- insects and birds acting as agents of pollination
- animals acting as agents of fruit and seed dispersal
- trees providing shade and shelter to animals and other plants
- bacteria and fungi helping to decompose dead organic matter
- symbioses (singular: symbiosis) – relationships between organisms where one or both partners benefit, e.g. lichens (association between a fungus and an alga)
- control of pests by specific predators.

Harmful biotic factors include:

- plant-eating animals (herbivores), such as herds of goats which feed on and may destroy plants
- flesh-eating animals (carnivores) which feed on other animals
- some organisms (parasites) which live on or in another living organism (host) and may cause considerable harm, e.g. large numbers of herbivores can be affected by liver fluke in a wet season. This biotic interaction is called **parasitism**. It is a close relationship between two organisms. The host suffers while the parasite gains.

Organisms can compete for the same resource in an ecosystem. An example of **competition** in an ecosystem is in a tropical rain forest where a tree grows taller than the surrounding trees and so is able to absorb more sunlight. However, less sunlight is then available for nearby trees that are shaded by the taller tree. Another example is competition between cheetahs and lions in an ecosystem. Since both animals feed on the same prey, they are negatively impacted by the presence of the other because they will have less food.

People have a great deal of influence on their surroundings, much of it harmful. Examples include felling of trees for timber, clearing of land for agriculture and building purposes and dumping of waste materials and other pollutants. Misuse of agrochemicals, such as fertilisers, pesticides and herbicides, damage the environment. All of these result in the destruction of vast areas of natural habitats, rendering many animals and plants homeless and threatening their existence.

Types of ecosystem

There are natural and artificial ecosystems comprised of both **aquatic** (water) and **terrestrial** (land) types of habitat. The **natural** ecosystems include fresh water, marine, estuarine, lake, main forest, savannah and desert. The **artificial** ecosystems include farmland, man-made lakes and roads.

Aquatic ecosystems

An aquatic ecosystem may be either fresh water or marine (salt water).

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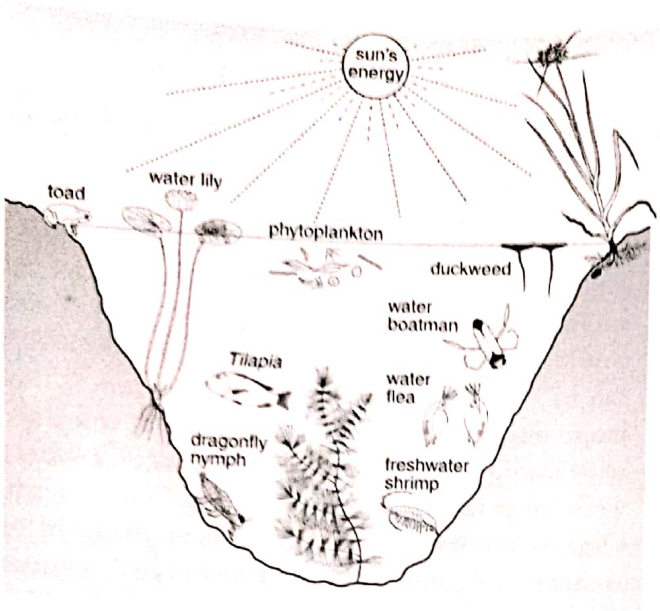


Fig 1.168 A pond ecosystem.

Fresh water

This is a salt free watery environment, e.g. pond, lake, stream or river. In ponds (Figure 1.168) and lakes organisms are not subjected to the moving effects of water currents. Some of the organisms live on the water surface. Among these are microscopic algae, such as diatoms and blue-green bacteria. They form the **phytoplankton** of the pond. Phytoplankton are microscopic producers. Other free-floating organisms are *Spirogyra* and water plants such as duckweed and water lettuce. Mosquito larvae and pupae and pond skaters also live on or just beneath the surface.

Other organisms are found just beneath the water surface, e.g. water fleas and freshwater shrimps. These microscopic animals form the **zooplankton** of a pond or a lake. Zooplankton are the primary consumers of the ecosystem. Larger organisms, such as diving beetles, can be found at any depth in a pond or lake. Zooplankton provide food for freshwater fish, e.g. *Tilapia* and tiger fish.

Many plants live submerged in the pond. Water lily species are rooted in the soil at the bottom. They grow only in shallow water where sufficient light is available for photosynthesis. Among the plants which grow at the edge of ponds and lakes are grasses and some ferns.

Animals living at the edges of the pond include toads and crabs. A large number of animals live on the aquatic plants or in the mud at the bottom, as well as the sides of the pond. Pond snails crawl and feed on the plants. Many larvae, worms, leeches and flat worms are also found. These organisms form the **primary consumer** group. Prominent in the area are birds like herons, kingfishers and African spoonbills.

Dwellers in streams and rivers are similar to those in ponds and lakes. However, these organisms face the danger of being carried away by water currents. Some of the smaller animals hide themselves among the vegetation on the banks where the water flows more slowly. Some of them, for example, the larvae of the blackfly cling to stones or rocks. *Ancylus* is a snail with a smooth and nearly flat shell. Water easily flows over the shell without sweeping the snail away.

Marine

Marine ecosystems are made up of the seas, oceans, lagoons and estuaries. These habitats contain salty water.

The **intertidal zone** at the seashore is a marine habitat. This zone is the region between the water mark at low and high tides which is covered with water at high tide and becomes exposed to the air when the tide goes out (Figure 1.169).

The microscopic, free-floating organisms which make up the plankton in the surface waters of the intertidal zone are diatoms, protozoans, copepods (crustaceans), snails and the larvae of different animals. Organisms which live in the habitat are adapted for aquatic life.

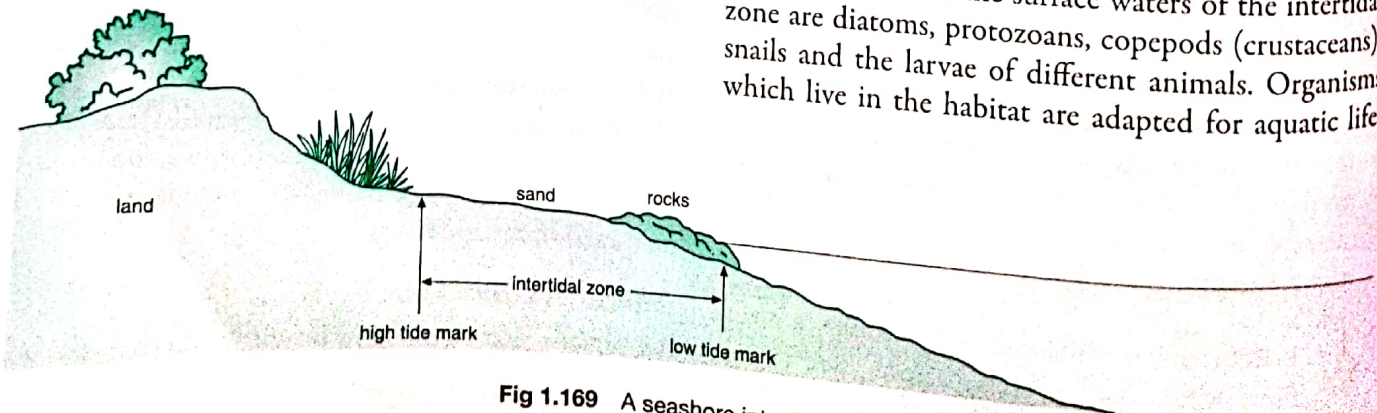


Fig 1.169 A seashore intertidal zone.

They also have adaptations which enable them to survive when they are exposed to air during low tide. On a sandy intertidal zone, as the tide recedes, some animals dig into the sand; others withdraw into their holes. The starfish uses its tube feet to bury itself, while molluscs use their specialised foot for digging into the sand. Many crabs and annelids (worms) are active burrowers.

Some animals avoid drying up by withdrawing into a protective shell and enclosing some water with them. Examples are limpets and barnacles. These and other animals have various adaptations for holding on to the rock surface. A limpet's shell fits close to the rock surface and its foot attaches it firmly by suction. Barnacles, unlike limpets, are permanently cemented to the rock surface. Mussels are attached by strong threads. Sea anemones and sea urchins also attach themselves firmly to the rock surface. A number of organisms are trapped in rock pools at low tide. The flattened bodies of crabs allow them to move easily into rock crevices. Small fish, starfish and other animals may also be found in intertidal rock pools.

A number of shore birds may be found feeding along the intertidal zone, including the sand piper and the black tern. The ghost crab is also found on many sandy shores in the tropics.

Many types of algae (seaweeds) are found in the intertidal zone of rocky shores. They have holdfasts which attach them permanently to rocks. Examples are green sea lettuce and brown algae. Some, like *Sargassum*, have air filled bladders which enable the branches to float. There are also filamentous algae.

Estuaries are coastal ecosystems where sea water and fresh water meet. The fresh water comes from rivers and streams and runs off from the land when it rains.

Sampling techniques in an aquatic habitat

Figure 1.170 shows some examples of equipment that may be used to sample an aquatic habitat. The long-handled net can be used either to skim across the surface to collect surface animals and floating organisms, or used to collect plant and animal specimens from various depths in the water. The conical, fine mesh plankton net can be used for collecting the very small organisms, both plant (phytoplankton) and animal (zooplankton), that inhabit the surface waters of salt water and freshwater habitats. As the net is moved across the surface, the plankton collects in the container at the tip and the water filters through the mesh. Larger organisms can be trapped with a wicker-work trap, used in conjunction with bait. This has a 'one-way' opening which prevents the animals from escaping once they have entered the trap. Figure 1.171 shows some common freshwater animals and can be used to help with identification.

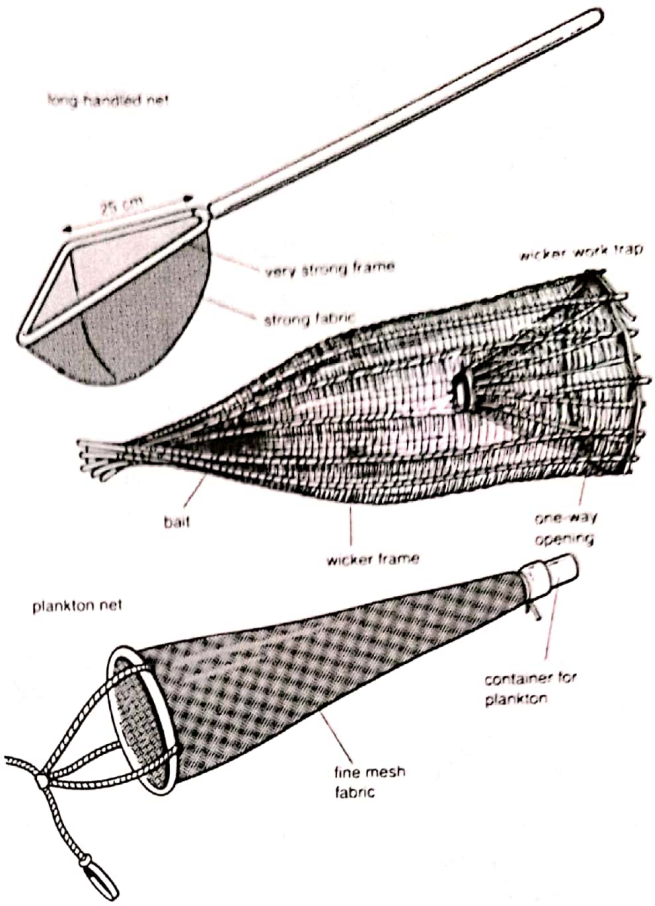


Fig 1.170 Equipment for sampling aquatic habitats.

ACTIVITY 2 Studying an aquatic habitat

1. Choose a suitable habitat for your study. This may be a pond, stream or seashore.
2. Draw a sketch of the area to be studied and label any special features.
3. Using the sampling techniques already described, collect and identify as many different animals as possible from the area. Collect and identify plant species also. You will need to use reference books to help you with this stage.
4. Measure some important abiotic features, e.g. temperature and pH of the water.
5. Use reference books to find out about the feeding habits of the animals identified. Try to work out how the organisms are interrelated.

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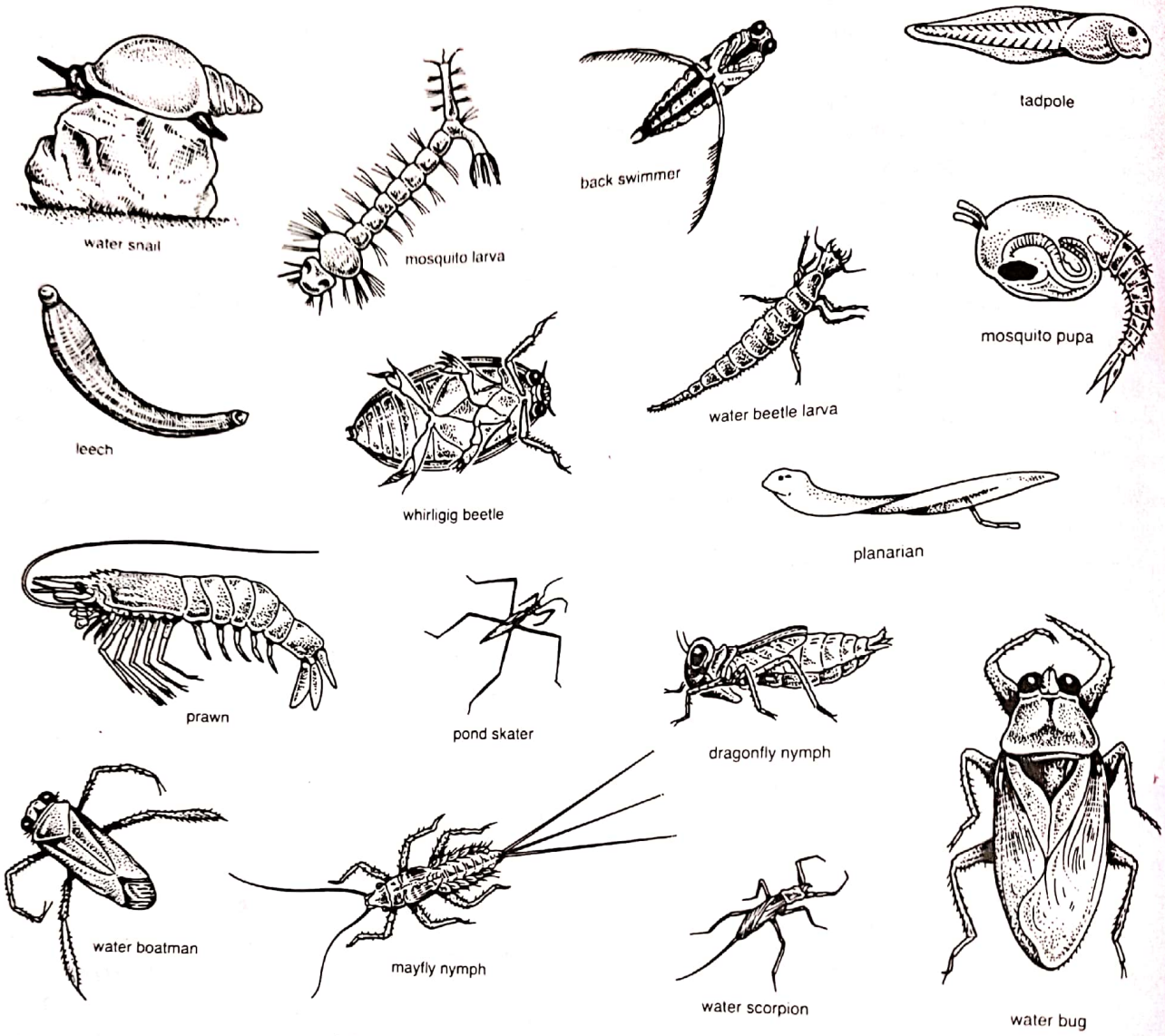


Fig 1.171 Some common freshwater animals.

6 Study the habitat carefully to see if you can find any other relationships between the organisms. Have people had any effect on this habitat?

7 Discuss your findings with other members of the class.

Terrestrial ecosystems

Terrestrial habitats vary according to the type of vegetation. In forests large trees are abundant; grasslands (savannah) contain more grasses than trees; and deserts have little vegetation. The type of vegetation depends on physical factors, such as the amount of rainfall, temperature and soil type. For example, there are thick rain forests in tropical Africa where rainfall is very high, whilst the savannah regions have low rainfall.

The distribution of animals in different habitats depends partly on the vegetation and partly on climatic factors.

Rain forest

In a tropical rain forest rain falls throughout the year, giving a high yearly total. Trees are the most abundant plants. Other plants are found growing on, around or under the trees. The crowns of these trees form three layers, storeys or canopies (Figure 1.172).

Trees above 30 m are called emergents. The middle canopy is formed by trees about 30 m high and trees about 15 m high make up the lower storey. Smaller plants found on the forest floor consist of the seedlings of forest trees, short palms, shrubs, herbs and ferns.



Fig 1.172 Profile of a tropical rain forest.

Many epiphytic plants, for example, ferns and orchids, grow in forests.

An **epiphyte** is a plant that grows on another plant and is supported by that plant. It does not take any food from the support (host) tree. Epiphytes are also called aerophytes or air plants.

Epiphytes grow near the top of emergent trees or on unshaded branches in the middle canopy where there is enough light for photosynthesis. They usually grow in the rotting organic material that forms in the angles between large branches. Examples of epiphytic ferns are the stag-horn fern and orange-spot fern. In the stag-horn fern water which trickles down the tree trunk and collects between the dead brown leaves and the trunk. This contains mineral salts which the plant absorbs. The green leaves are photosynthetic.

Epiphytic orchids have long, spongy roots through which they can absorb water that runs down the trunk. Some of the roots are spread out over the tree trunk, attaching the orchid firmly to the host. Others hang in the air and absorb moisture from it. The thick, leathery leaves enable orchids to reduce loss of water by transpiration.

Another type of plant found in the forest is a climber. Some are found in the lower layers of the trees. Others are the large lianes which climb high into the upper canopy. Climbing is done usually by twining. Some climbers have roots, hooks and tendrils.

A very large number of animals live in rain forests. Examples of ground animals are tortoise, monitor lizard, gaboon viper (reptiles) and Latham's francolin (bird). Mammals include Ogilby's duiker, mongoose and two-spotted palm civet. There are also mice and rats.

Most of the animals live in the trees and are termed **arboreal**. These include grasshoppers, butterflies, ants and spiders. Tailor ants make their nests from leaves which they pull and stick together with secretions produced by their larvae. Tree frogs have suckers on their toes with which they climb trees. The adult lives in trees overhanging a river or a pool of water. It lays eggs on a tree trunk or a leaf surface. When the eggs hatch, the tadpoles wriggle and fall into the water below. Here they feed, grow and develop into adults.

Among the reptiles are chameleons, whose opposable fingers and toes and prehensile (capable of grasping) tail enable them to climb; geckos, which have sticky pads on their palms for climbing; and snakes, such as the green mamba, whose elongated bodies enable them to twist around branches of trees.

Common birds include the African grey parrot, the touracou, the wood owl and several species of hornbill. They feed on fruits of the forest trees and nest in holes made in the same trees.

Arboreal mammals include bats, monkeys (such as mona and colobus monkeys) and squirrels. Other mammals are the common pangolin and the leopard.

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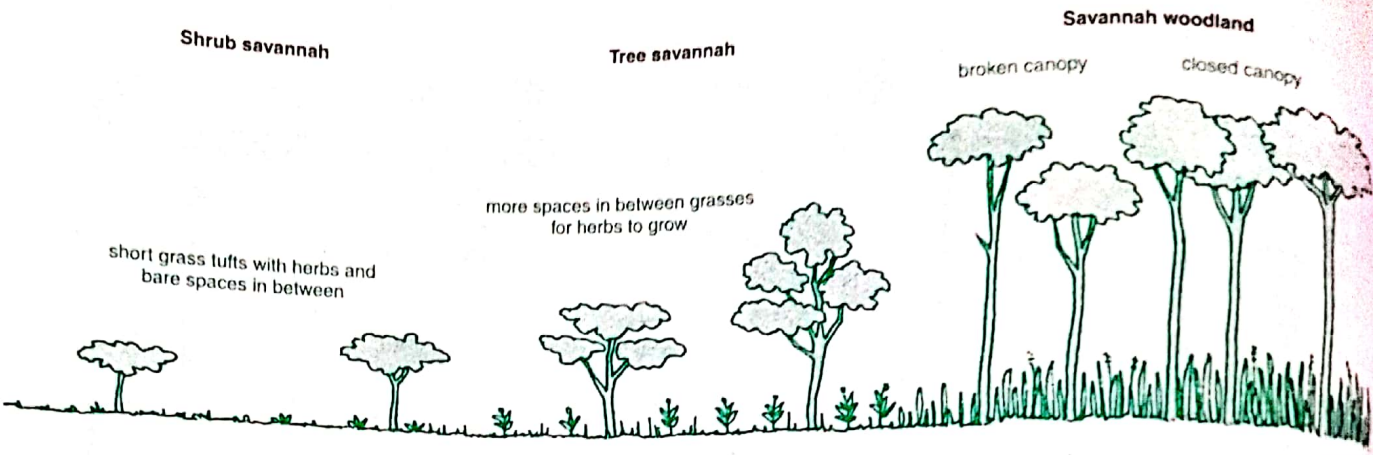


Fig 1.173 Savannah zones.

Savannah

This habitat is mainly grassland vegetation with shrubs and small trees, except for the baobab tree. The vegetation depends mostly on the amount of rainfall and the duration of the dry season. Figure 1.173 shows three types of savannah zone.

The change that occurs on passing from one zone into another is due to decreasing rainfall, increasing drought from south to north and annual burning of vegetation for farming purposes. Because savannah grasses abound, the majority of the savannah animals are herbivores. Smaller ones include mice, rats, squirrels and hedgehogs. Larger herbivores are antelopes, zebras, giraffes and elephants.

Other familiar savannah organisms are ants, locusts, termites, grasshoppers, vultures, pigeons, egrets, lizards, geckos, chameleons and various snakes.

Desert

A desert is a landscape form or region that receives very little precipitation. Deserts are defined as areas that receive an average annual rainfall less than 250 mm.

Artificial ecosystem

Human activities, such as farming, digging and road construction, may adversely alter the ecosystem. The farmlands may have species which are quite different from earlier species. The holes left after digging (e.g. through mining activity and quarrying) could collect water when rain falls to become 'man-made' lakes. Aquatic life may spring up.

Roads can separate slow moving animals on either side.

Sampling techniques in a terrestrial habitat

Quadrat

A quadrat (Figure 1.174) is a square wooden frame, which may be divided into smaller squares by means of string or wire fastened across the frame. The size of the frame depends on the area under study and the size of the organisms being sampled.

The quadrat is normally thrown (carefully!) at random within the habitat and, where it lands, the area of ground enclosed by the quadrat is carefully studied. This normally involves counting the numbers of each species of plant within the frame (those partially enclosed are usually counted as 1/2). This random sampling method is repeated several times, thus obtaining a list of common species together with percentage cover.

Another method of sampling or plotting plant distribution involves using a quadrat in conjunction with a line transect. A string is laid down in a straight line across all or part of the habitat. Sampling of

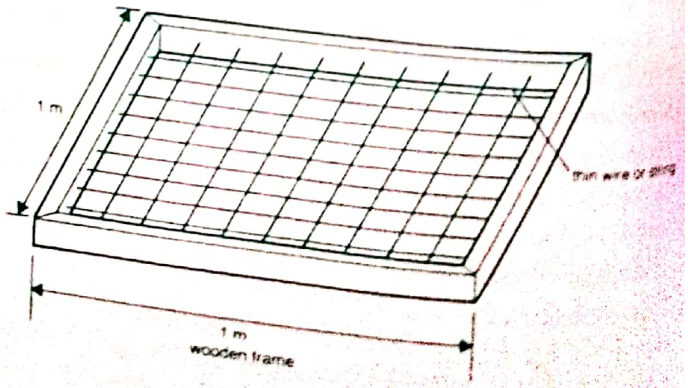


Fig 1.174 A quadrat.

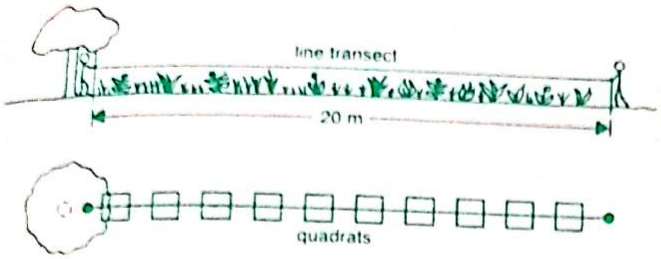


Fig 1.175 A line transect showing the positions of the sampling stations.

vegetation is then carried out by placing quadrats at regular intervals along the string (Figure 1.175).

Pitfall trap

Quadrats can only be used successfully for sampling vegetation. A pitfall trap is one way of sampling populations of small animals (usually invertebrates) in the habitat. A simple trap is just a hole in the ground with straight sides, containing food as bait. A large jar makes a better trap as the sides are smooth and slippery and are more likely to prevent escape (Figure 1.176).

Traps are placed randomly within the habitat and are examined regularly (at least once a day). Any organisms in the trap are collected, identified, counted and then released. Large traps may be used to sample small animals and lizards.

Small animal specimens, e.g. ants, found amongst leaf litter, on vegetation and in cracks and crevices, can be collected with the aid of a **pooter**. A **butterfly net** may be used to catch insects on the wing. Insects on the ground, and also some land vertebrates, can be trapped with a different type of net, called a **sweep net**. These items are illustrated in Figure 1.177.

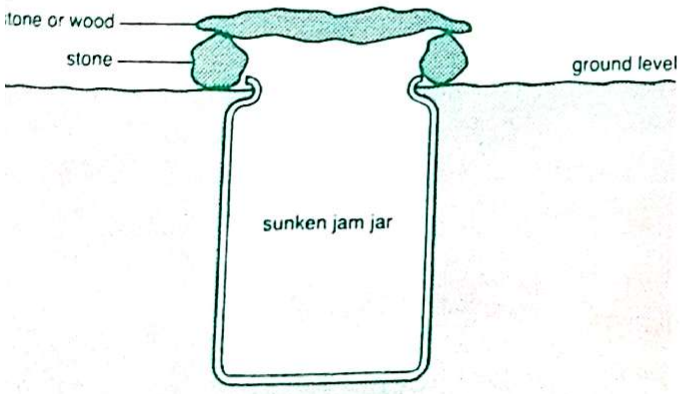


Fig 1.176 A pitfall trap.

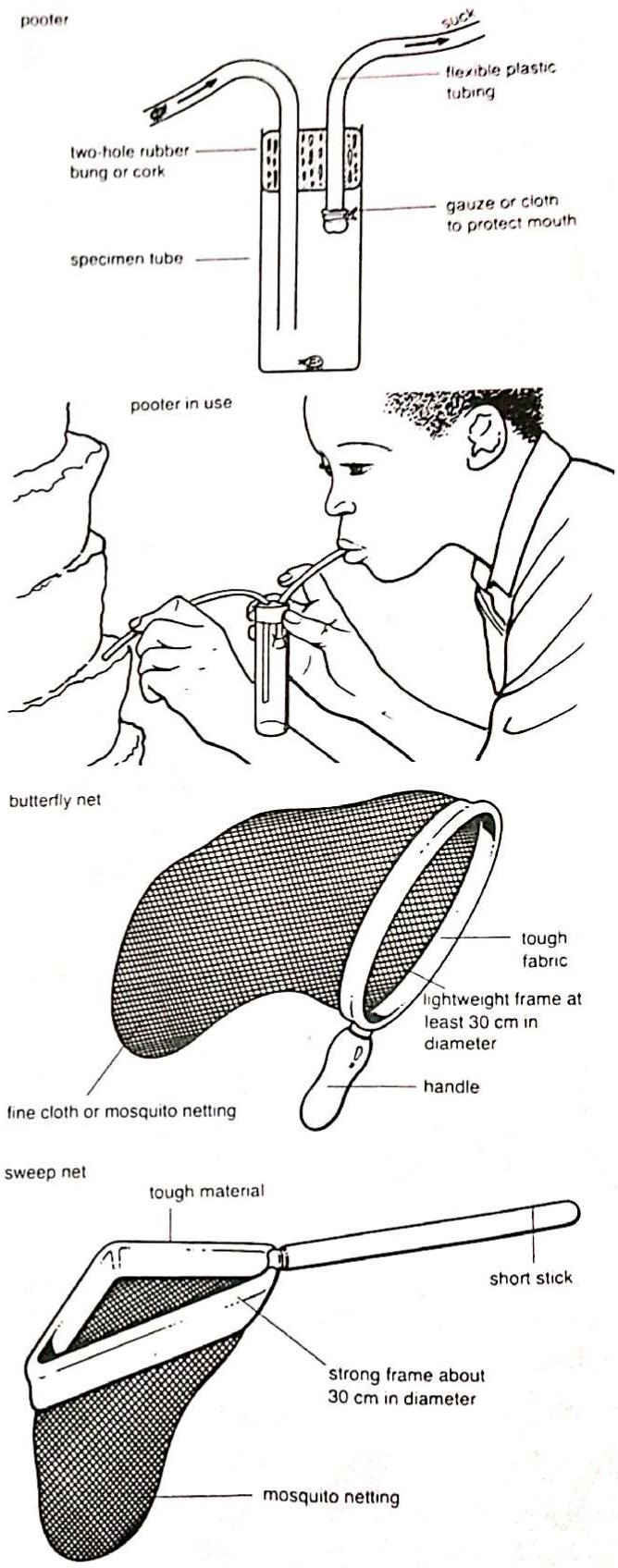


Fig 1.177 Equipment for sampling organisms in a terrestrial habitat.

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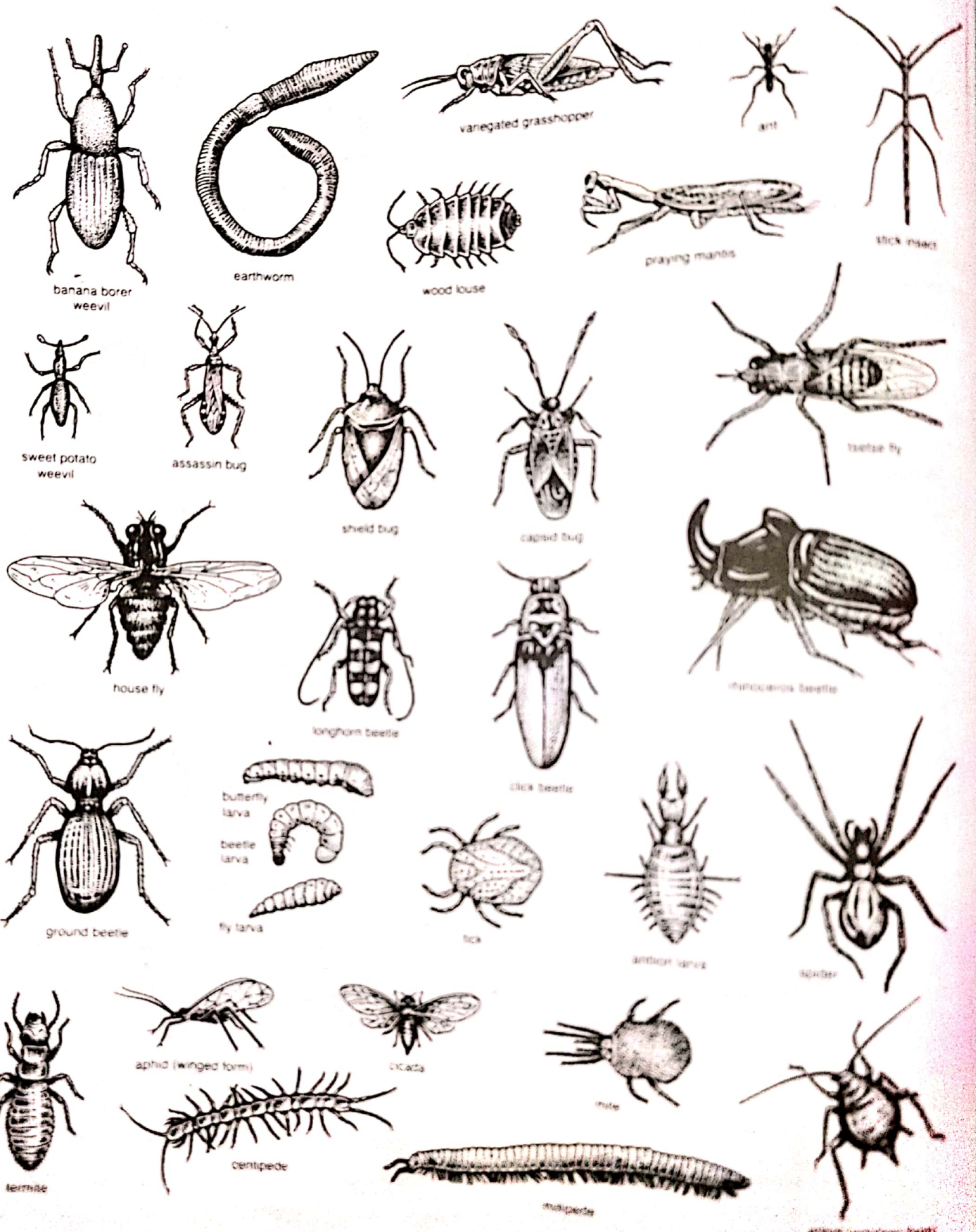


Fig 1.178 Common types of invertebrates found in terrestrial ecosystems

Figure 1.178 illustrates some common invertebrates found in local terrestrial habitats. It can be used to help with identification when carrying out ecological studies.

ACTIVITY 3 Studying a terrestrial habitat

1. Choose a suitable habitat for your study. This may be a rain forest, savannah or smaller area, such as the school grounds.
2. Draw a sketch of the area to be studied and label any special features.
3. Using the sampling techniques already described, collect and identify as many different small animals as possible from the area. Identify larger animals. Collect and identify plant species also. You will need to use reference books to help you with this stage.
4. Measure some important abiotic features, e.g. rainfall, air temperature, wind speed and direction, light intensity in different areas and pH of the soil.
5. Use reference books to find out about the feeding habits of the animals identified. Try to work out how the organisms are interrelated.
6. Study the habitat carefully to see if you can find any other relationships between the organisms. Have people had any effect on this habitat?
7. Discuss your findings with other members of the class.

Interrelationships in an ecosystem

Food chains

Animals and plants within a particular habitat are linked through their feeding habits, i.e. plants are eaten by animals and these animals are in turn eaten by other animals and so on. A series of organisms linked in this way makes up a food chain. These are biotic interactions.

A **food chain** is a series of organisms in an ecosystem which are linked through their feeding habits. Energy containing carbon compounds (produced first by plants or other photosynthetic organisms) is transferred from one organism to another.

Food chains trace the transfer of energy from one organism to another. This energy originates from sunlight and is incorporated by green plants into organic compounds by the process of **photosynthesis**. Green plants manufacture their own organic food and, because of this, they are called **producers**. They form the base of all food chains. Animals need to eat other animals and/or plants in order to obtain energy. Animals are therefore called **consumers**.

Herbivores (plant-eaters) are called **primary consumers** because they are the first consumers in a food chain. Some examples are cattle, fruit bats, locusts and parrots. Most primary consumers are preyed upon (eaten by) carnivores (flesh-eaters). These animals are called **secondary consumers**. Some examples are dogs, cats, leopards and snakes. Tertiary consumers are animals that feed on secondary consumers. Examples are hawks and large carnivores, such as lions. Some animals have a mixed diet of plant and animal food. They are called omnivores, e.g. people. Omnivores can therefore be both primary and secondary consumers in a food chain.

Food chains always follow the same pattern:

producer → primary consumer → secondary consumer → tertiary consumer

The arrow indicates the direction of energy flow. A food chain may be short, consisting of only two links, e.g. maize → human or it may consist of three or more links, e.g.

grass → zebra → lion

grass → earthworm → frog → hawk

Because of energy loss at each transfer, food chains rarely have more than four links.

Another vital group of organisms, not always mentioned in food chains, are the **decomposers**. These are bacteria and fungi that obtain their energy by breaking down dead organic matter and absorbing the simple food substances produced. Decomposers play an important role in returning essential nutrients to the soil. These, in turn, are reabsorbed into the roots of green plants and reused to synthesise organic food.

Energy flow in food chains

Light energy is converted to potential chemical energy in photosynthesis by green plants (producers). This is only about 1 per cent efficient as a great deal of energy is lost as follows:

- reflection by dust, by soil and from plants' surface
- absorption by clouds and soil
- plant respiration.

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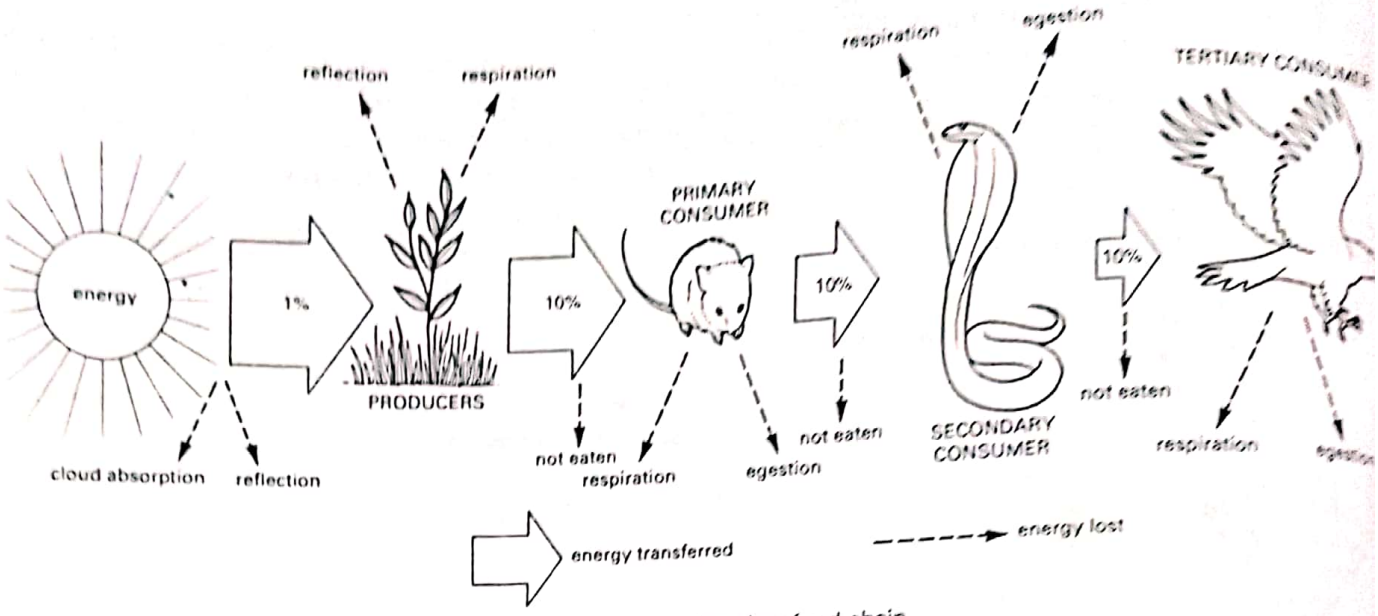


Fig 1.179 Energy flow in a food chain.

Energy transfer from the producer to the primary consumer is about 10 per cent efficient. This is because some food (energy) is not eaten, e.g. roots (not eaten by grazing cattle); some is not digested by the consumer and passes straight through, being egested in the faeces; some is respired.

Energy transfer between the primary consumer and the secondary consumer is about 10 per cent of the energy remaining. As shown in Figure 1.179, less energy is available further up the food chain at the higher consumer levels.

If you were faced with feeding a large number of people, it would therefore make sense to feed them with producers such as grain or rice, rather than feed the grain or rice to cattle or sheep first, before feeding the cattle and sheep to the people. Less energy is lost in the transfer and therefore more people can be supported on a mainly plant diet than on a mainly animal diet.

ACTIVITY 4 Discussing interactions in an ecosystem

1 Carefully study the diagram of the pond ecosystem in Figure 1.168.
2 Make a list of all the organisms that you can see.
3 Group the organisms into **a)** producers, **b)** consumers, **c)** decomposers.
4 *Work in groups* to discuss how each group depends on the other. Include the role of humans in your discussion.
5 In your group discuss the effect of non-living things (climate, soil, sunlight, etc.) on the ecosystem.
6 Construct three food chains using the organisms in the pond.

Food webs

A **food web** is a number of food chains linked together.

Interactions and associations within a community are such that simple food chains are seldom found. Instead, a number of food chains are linked to form a more complex food web. An example is shown in Figure 1.180.

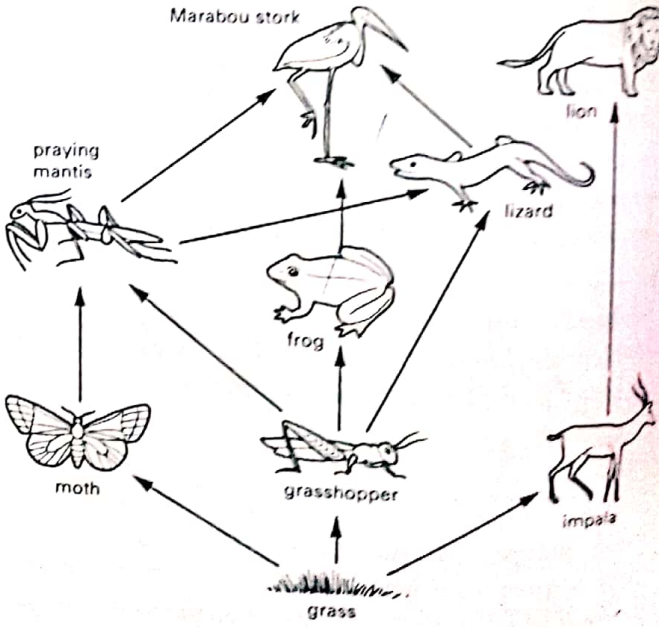


Fig 1.180 A simplified food web.

ACTIVITY 5 Constructing a food web

1 The information given below relates to interactions between individuals in a savannah community. Read it carefully.

Green plants include grasses, bushes and trees.

Herbivores include antelopes, zebra (ground feeders), giraffe and elephant (higher level feeders), beetles and grasshoppers.

Carnivores include cheetahs (feed mainly on smaller herbivores), lions (feed on all herbivores except elephants), jackals, hyenas and vultures (feed on remains of herbivores killed by other carnivores), and insect-eating birds.

Decomposers of dead plant and animal material include fungi and bacteria.

2 Group the organisms named in 1 into producers, primary consumers, secondary consumers, tertiary consumers and decomposers.

3 Use the information to construct a food web similar to that in Figure 1.180.

Self check

For questions 1 to 8, choose the letter that refers to the correct option.

1 Which of the following best defines the term 'population'?
- **A** people and other organisms living in a given area
- **B** people living in a given area
- **C** people and a few organisms living in a niche
- **D** people and a few organisms living in a biome

2 Organisms that form the phytoplankton of a pond are:
- **A** water lily species
- **B** fish
- **C** diatoms and blue-green bacteria
- **D** toads and crabs

3 A quadrat is used to sample:
- **A** floating organisms of a marine habitat
- **B** floating organisms of a freshwater habitat
- **C** land animals
- **D** land vegetation

4 Temperature is an example of:
- **A** a biotic factor
- **B** an abiotic factor
- **C** a secondary consumer
- **D** a producer

5 The food chain grass → sheep → man includes:
- **A** producer, secondary consumer and tertiary consumer
- **B** primary consumer, secondary consumer and tertiary consumer
- **C** primary consumer, secondary consumer and decomposer
- **D** producer, primary consumer and secondary consumer

6 Energy transfer between secondary consumer and tertiary consumer is:
- **A** 1 per cent efficient
- **B** 10 per cent efficient
- **C** 50 per cent efficient
- **D** 60 per cent efficient

7 Decomposers are organisms made up of:
- **A** animals and plants
- **B** animals and fungi
- **C** bacteria and fungi
- **D** bacteria and plants

8 Producers are:
- **A** plants that manufacture their own food
- **B** animals that manufacture their own food
- **C** animals that need organic food material
- **D** plants that need organic food material

9 Explain, with an example where possible, the following terms:
- **a)** ecology
- **b)** biosphere
- **c)** habitat
- **d)** environment
- **e)** community
- **f)** population
- **g)** ecosystem
- **h)** biome
- **i)** zone
- **j)** abiotic factor
- **k)** biotic factor producer
- **l)** primary consumer
- **m)** secondary consumer
- **n)** decomposer.

10 Look at Figure 1.180 and answer the following:
- **a)** Name a primary consumer.
- **b)** Name a secondary consumer.
- **c)** Name a tertiary consumer.
- **d)** If the grasshoppers were lost, suggest one possible effect on the moth population. Explain your answer.
- **e)** What is the original source of energy for this food web?

11
- **a)** How efficient is the energy transfer between producers and primary consumers?
- **b)** Give two ways by which energy can be lost between one stage of a food chain and another.

12 State one use for each of the following:
- **a)** pitfall trap
- **b)** wicker-work trap
- **c)** sweep net
- **d)** quadrat
- **e)** long-handled net.

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2 Atmosphere and climate change

Learning objectives

After studying this unit, you should be able to:

1 describe the various regions of the atmosphere
2 outline the effects of human activities on the atmosphere
3 describe the major pollutants of the atmosphere and their effects
4 explain the greenhouse effect on climate change
5 explain the causes and effects of the depletion of the ozone layer
6 explain the causes and effects of acid rain.

Background information

The Earth is spherical in shape. Its atmosphere is a mass of spherical gas layers surrounding its surface (Figure 1.181). The atmosphere is kept in place by the attraction of the Earth's magnetic field so that the gases do not escape into space. The sun, as the main and constant source of energy, occupies a suitable distance from the Earth's surface, thus making the Earth the only known planet that supports plant and animal life. The layers are of different thicknesses and unique in gas composition, temperature, humidity and other properties that make the atmosphere different from that of other planets.

The atmosphere, as it exists now, has developed over millions of years into a stable and balanced system. The atmosphere, with its various gas layers, plays a useful role in maintaining the life activities of plants and animals and protects them and the environment. Scientists believe that without this special type of atmosphere there may not be life on Earth or not in the form it is now. Human activities that disrupt, destroy or pollute the Earth's environment and atmosphere put

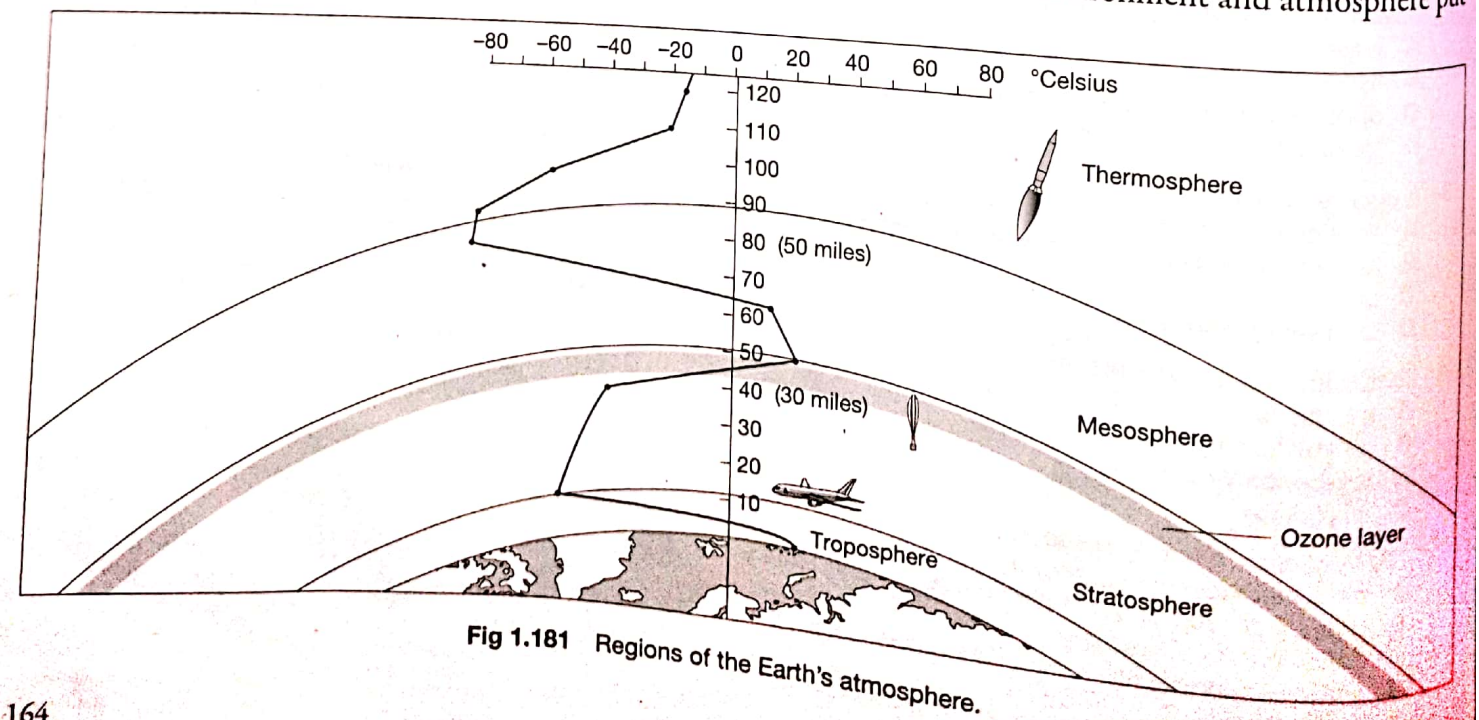


Fig 1.181 Regions of the Earth's atmosphere.

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the ability of the Earth and its atmosphere to sustain and protect plant and animal life at risk. It is, then, human civilisation that is at risk.

The atmosphere

ACTIVITY 1 The atmosphere

1 Carefully study the diagram of the atmosphere in Figure 1.181.

2 **a)** Is the temperature of each region the same?
b) What is the temperature on Earth?
c) Is it different from the temperature where you live? Explain this.

3 In which region can **a)** the lowest temperature **b)** the highest temperature be found?

4 What is the thickness, in km, of **a)** the mesosphere **b)** the troposphere?

5 Predict, with reasons, which of the regions would be most suitable to sustain human life.

The main regions of the Earth's atmosphere are:

- troposphere
- stratosphere
- mesosphere
- thermosphere.

Troposphere

The troposphere is the immediate region around the Earth's surface. It ranges from 0–10 km in length. In Ghana day temperature at the coast may be around 29°C. The temperature decreases as you get higher. The gas composition on the surface of the Earth is nitrogen gas, N_2 – 78 per cent, oxygen gas, O_2 – 21 per cent, carbon dioxide gas, CO_2 – 0.036 per cent, inert gases, water vapour and other trace gases – 1 per cent. The gases are most dense at the Earth's surface, exerting a force per unit area or an atmospheric pressure of approximately 100 kpa. The air, soil and features, climate and atmosphere create a suitable temperature and climate to support plant and animal life. Air masses in the troposphere are mainly responsible for the weather on Earth.

Stratosphere

It is the region of the atmosphere that extends from 10–50 km. The higher limits are occupied by the **ozone layer** which filters out a large amount of harmful ultraviolet radiation from sunlight before it reaches the Earth. The average temperature is higher than in the troposphere but rises sharply in and near the ozone layer due to absorption of the sunlight. There is a little amount of air and this moves in a horizontal direction making it suitable for air travel.

Mesosphere

It covers the region from 50–90 km of the atmosphere. The temperature decreases sharply to the lowest in the Earth's atmosphere to about –85°C. Since air is sparse in this region and beyond, there is no weather here.

Thermosphere

This is the region above 90 km. In this region oxygen absorbs a lot of sunlight as distance increases. Temperature starts to increase in this region and may reach as high as 1000°C at 1000 km. Starting from the mesosphere into the thermosphere and beyond (60–1000 km), increasing amounts of gaseous ions or plasma are found due to the high temperatures.

Human activities and their effects on the atmosphere

The Earth and its atmosphere have developed over many millions of years into a system in balance. The system works in a way to sustain life and protect the environment. There are many human activities that produce effects that overturn the balance on which life and the environment depend.

- **Transportation** – transportation activities need energy. Fossil fuels, such as coal, natural gas, petrol and kerosene, are burnt to produce the energy. For example, when vehicles and airplanes burn fossil fuels carbon dioxide gas, which is a greenhouse gas, is produced.
- **Defence** – the use of chemical and biological weapons of mass destruction in wars and their stockpiles for defensive purposes cause injury to plants and animals in many ways including death. They cause injury when inhaled, come into contact with the skin or eaten as contaminated food.

  Examples of destructive chemical weapon sources are: phosgene (chokes), chlorine (destroys cells), hydrogen cyanide (blocks oxygen reaching

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the blood), mustard gas (causes blisters of the skin, eyes and lungs leading to respiratory failure) and radioactive fallout (e.g. destroys cells leading to cancerous diseases). Others are herbicides, e.g. Agent Orange (defoliant) and nerve agents, e.g. sarin, soman and VX (they block the sending of nerve messages in the human body and can cause death).

Biological weapons are produced from bacteria or microorganisms, viruses and fungi. Examples are anthrax (used in posted letters) and botulin toxin. They cause diseases.

- **Industrialisation and agriculture** – industrialisation since the eighteenth century has brought about large-scale factory manufacturing of goods by machines. The large-scale burning of fossil fuels to provide energy for machines produces increasing greenhouse gases in the atmosphere. Industrialisation still continues with positive and negative effects on humans and their environment. Manufacturing and use of many chemicals pollute the atmosphere and the Earth's surface, e.g. chlorofluorocarbons, plastics and agricultural chemicals, such as fertilisers, weedicides and pesticides that pollute and poison water bodies and cause extensive loss of vegetation.
- **Deforestation** – the clearing of forests or vegetation for wood, farming, building or other human activities. In West Africa excessive felling of trees for timber or fuel without replacement, bush burning as a method of hunting and land preparation, mass clearing of land for human settlement, industrialisation and construction of infrastructure, such as roads and communication networks, all contribute to deforestation. Deforestation may result in the decay of plants and the release of carbon dioxide into the atmosphere, but the reduction of trees and vegetation to absorb carbon dioxide allows a greater amount of carbon dioxide in the atmosphere to promote global warming. Deforestation therefore causes a net increase of carbon dioxide in the atmosphere. Deforestation also renders houses, schools, office buildings and other infrastructure unprotected from strong winds which may lead to their destruction.

Atmospheric pollution

The major pollutants of the atmosphere are gases: oxides of nitrogen, sulphur and carbon. Lead metal and compounds, e.g. lead spoons, lead paints, lead rods in vehicle batteries and leaded petrol, are also pollutants when vaporised, causing nervous disorders in humans and learning disabilities in children. Lead ore mines which produce the lead metal and lead products are sources of lead poisoning. No leaded petrol is sold in Ghana now.

Surface mining generates dust particles in large quantities, turning clear, odourless air into polluted air that kills plants, harms health and damages property. If inhaled, the dust particles cause respiratory problems in humans and livestock. They can also cause irritation to the eyes. When the dust particles settle on the leaves of crops, both photosynthesis and transpiration are drastically reduced, leading to poor plant growth.

Diesel engines used in mining operations produce a lot of air pollutants, such as nitrogen oxide, carbon monoxide and carbon dioxide. These pollutants cause the destruction of the ozone layer and the formation of acid rain. For example, when nitrogen oxides combine chemically with rain water they produce trioxonitrate(V) and dioxonitrate(III) acids which kill fish, and damage plants and property. Nitrogen oxides may also combine with hydrocarbons to form smog which irritates the eyes, damages the lungs when inhaled, causes headaches and damages plants.

While carbon dioxide traps infrared rays to cause global warming, carbon monoxide causes headaches, dizziness and poisoning in humans. In addition, the smoke from engines and dust particles together cause poor visibility, leading to accidents. They also cause some physiological and psychological changes in humans, e.g. asthma, bronchitis and irritability.

Greenhouse effect, global warming and climate change

A **greenhouse** is a building made of glass or plastic which can trap sunlight to heat its interior and also allows the heat to escape slowly into the atmosphere (Figure 1.182). The temperature, light, moisture and other essential conditions for plant growth can be regulated in a greenhouse to allow plants to grow throughout the year. It is this idea which has been likened to the way the atmosphere helps to keep the Earth's surface warm by trapping radiated heat from the Earth's surface.

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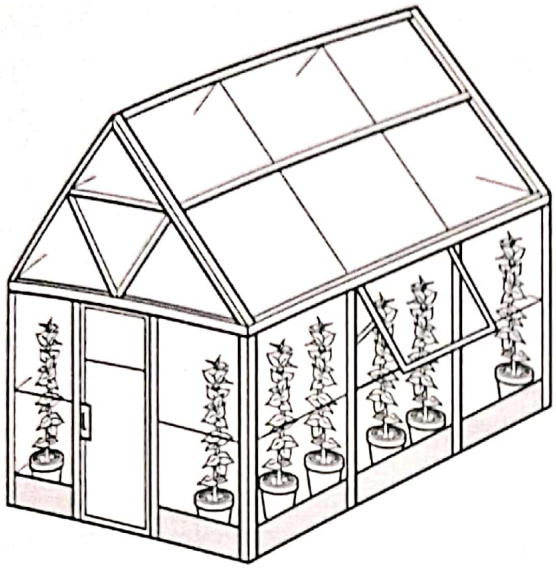


Fig 1.182 A greenhouse.

The **greenhouse effect** is the warming of the Earth's surface by undesirable increases in carbon dioxide, oxides of nitrogen, methane and water vapour in the Earth's atmosphere.

Through natural processes on the Earth's surface over millions of years, a mixture of gases made up mainly of carbon dioxide, oxides of nitrogen, methane and water vapour have built up in the Earth's atmosphere. These gases are the **greenhouse gases**. Carbon dioxide, in particular, is produced through respiration of animals, decay of plant and animal matter and eruption of volcanoes. It is used up by plants in photosynthesis, absorbed by oceans, lakes, rivers and organisms in the carbon cycle to establish fixed amount of carbon dioxide in the atmosphere (0.034 per cent or 340 ppm).

Sunlight rays warms the Earth's surface. Some of the warm air is radiated back into the atmosphere in the form of infrared light. The greenhouse gases trap some of this infrared radiation from the Earth's surface as heat. It is this trapped heat that keeps the Earth warm.

The natural greenhouse effect maintains the Earth's surface at an average temperature of 15°C, a temperature suitably warm for human and plant life; otherwise it would be about 33°C colder and life could not be sustained as it is now.

Humans need and use energy to carry out their activities. Carbon containing materials, such as fossil fuels, are burnt to provide the energy. They include natural gas, petrol, kerosene and other hydrocarbons from petroleum, coal, wood and wood products and solid wastes. The burning processes have increased and are increasing carbon dioxide and the other greenhouse gas levels in the atmosphere since the industrial revolution in the 1750s. Large-scale deforestation has also reduced trees and vegetation that absorb carbon dioxide, thereby increasing the carbon dioxide level in the atmosphere.

In all, the amount of carbon dioxide and the other greenhouse gases in the Earth's atmosphere is increasing more than natural processes can absorb. The main human activities that do this are the burning of fossil fuels, industrial activities, bush and forest fires and deforestation. Since the 1750s, carbon dioxide levels, for example, have increased by 31 per cent. The increased amount of greenhouse gases in the atmosphere traps more infrared radiation from the Earth's surface. This in turn warms the Earth's surface more than normal and increases its average temperature (Figure 1.183).

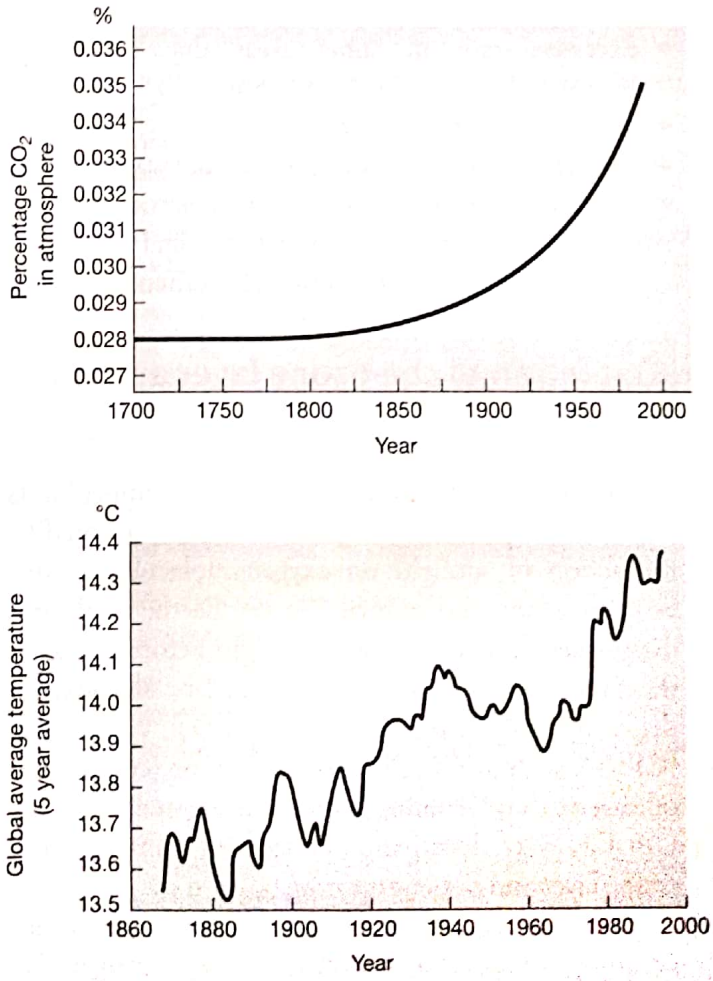


Fig 1.183 Global warming **(a)** Percentage carbon dioxide in the atmosphere **(b)** Global average temperatures.

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The increase in the warming of the Earth's surface by increased levels of carbon dioxide and other greenhouse gases in its atmosphere is called **global warming**.

Global warming is predicted to cause unusual (freaky) weather or climate changes all over the Earth. It will bring unusual effects on plants, animals and the environment, including the following:

- Melting of icecaps in the polar regions and mountain glaciers: this will cause ocean levels to rise, flooding of low coastal areas and the disappearance of some islands and atolls.
- Droughts and desertification in some areas caused by the warmer air.
- Increase in the number of storms, e.g. hurricanes and cyclones, due to warmer air above the sea moving to meet the colder air in the atmosphere.
- Loss of productive farming land leading to famine.
- Loss of forests and accompanying biodiversity.
- Excessive rain in some areas due to greater evaporation and an increase in humidity.
- Increased forest and bush fires.
- Decrease in the water levels of onshore water bodies.
- Increase in diseases caused by warmer conditions in some areas, e.g. malaria and cerebrospinal meningitis will spread towards northern and southern regions.

Depletion of the ozone layer and its effects

The ozone layer is in the atmosphere, in the upper limits of the stratosphere (see Figure 1.181). It is formed by the action of sunlight on oxygen molecules. Ozone protects plant and animal life on Earth. It absorbs dangerous ultraviolet light in sunlight before it reaches the Earth's surface. It was discovered by scientists in the early 1970s when chlorofluorocarbon compounds (**CFCs**), such as CF_2Cl_2 and the **halons** (compounds of carbon) and combination of halogen atoms, e.g. CBr_2CF, were destroying or depleting the protective ozone layer and thereby creating holes in it.

CFCs are used as cleaning solvents in electronics, aerosol propellants, air conditioning and refrigeration gases. They are used to blow plastics into shapes and halons are used in fire extinguishers. When used on Earth, they drift up into the ozone layer. Under suitable conditions of low temperature, low pressure and in the presence of the sun's ultraviolet light, the CFCs and halons break up, releasing chlorine atoms that react with the ozone molecules and destroy them. The reaction creates new chemicals that repeat the destruction of millions of ozone molecules.

The reduction in the ozone layer by the reaction of the chlorine atoms from CFCs and halons is known as **ozone layer depletion**. The depletion creates a hole in the ozone layer.

Ozone layer depletion or destruction allows the direct incidence of the harmful ultraviolet light from sunlight on to plants and animals on the Earth. Scientists have already observed the depletion of the ozone layer in the atmosphere of the Arctic, Antarctic and North American regions at certain times of the year. Many negative effects that are predicted on plants and animals include:

- skin cancers in humans and animals; wrinkled, hard and freckled skin
- eye damage and diseases
- damage to certain crops and plankton (tiny floating organisms that fish and other water animals feed on) resulting in damage to the marine food web
- increase in carbon dioxide levels in the atmosphere due to a decrease in plants and plankton that absorb it
- damage of the human and animal immune systems
- destruction of chlorophyll in green leaves, leading to food shortage.

It should be noted that CFCs and halons also contribute to global warming. International agreements have been signed by nations, including Ghana, to phase out the use of ozone depleting gases and use safer chemicals, such as hydrofluorocarbons (HFCs). HFCs do not contain the chlorine atom. In addition, because of the presence of the hydrogen atom, they are less stable and break down more easily before getting to the ozone layer.

ACTIVITY 2 CFC compliance check

1 Visit the workshop of a refrigeration mechanic.
2 Request to see the gas container that is used in refilling new gas when repairs are carried out.

3 a) Copy the name and formula of the gas used.
b) Is it a CFC or a HFC?

4 Check the back of refrigerators, old and newer ones, and find out the name or formula of its refill gas.

5 Write a short report to indicate whether the refrigerator in the mechanic's shop and in your home abide by the international agreement not to use ozone depleting CFCs. Discuss with your class.

6 a) Explain briefly how CFCs destroy the ozone layer.
b) State three effects of the depletion of the ozone layer.

Acid rain and its effects

Oxides of nitrogen and sulphur are formed when fossil fuels, such as coal, natural gas and petrol, are burned in factories, vehicles and power stations to provide energy. These oxides exist mixed with dry air or dissolved in rain water in the atmosphere to form acid rain. Acid rain contains dilute forms of the acids: tetraoxosulphate (VI) acid, H_2SO_4, and trioxonitrate (V) acid, HNO_3, which are corrosive and destructive to plants and animals and the environment. Acid rain clouds can be blown by winds across country borders to cause damage; hence, it is an international problem. Some of the negative effects of acid rain are:

- Acid rain makes the soil acidic. This damages plant root hairs and leaves, and nutrients are leached from the soil resulting in the death or stunted growth of trees.
- Lakes, rivers and other water bodies are acidified. This damages some organs of fish and other marine organisms and can result in their death.
- Corrosion of metals and wearing away of rocks, stones, marble and concrete structures is increased. For example, statues corrode and get disfigured.
- Paints fade and peel off surfaces.

ACTIVITY 3 Visiting a degraded forest

1 If possible, visit a nearby degraded forest to:
a) Observe and record evidence of soil erosion and poor growth of vegetation.
b) Identify water bodies and comment on the amounts of water they contain.
c) Observe the topsoil and comment on its structure, colour and components.
d) Attempt a count of wild animals seen.

2 Work in groups to write a group report on the visit.

Self check

For questions 1 to 6, choose the letter that refers to the correct option.

1 Which of the following human activities contributes to the greenhouse effect?
I setting bushfires
II burning of rubbish by city and village authorities
III making manure out of refuse and dead plants
IV gas emissions from thermal energy plants
A I, II, III and IV
B I, II and III
C I, II and IV
D II, III and IV

2 The nearest and farthest layers of the Earth's atmosphere are respectively known as:
A thermosphere and troposphere
B stratosphere and mesosphere
C troposphere and thermosphere
D mesosphere and thermosphere

3 Lead poisoning can cause which one of the following:
A food poisoning
B acid rain
C greenhouse effect
D mental retardation in children

4 Human activities are responsible for the following effects on the Earth or its atmosphere except:
A global warming, acid rain
B global warming, population increase
C population increase, acid rain
D increase in gravitational pull on the Earth, lead poisoning

5 The main sources of greenhouse gases are:
A water vapour, methane and hydrogen sulphide
B aerosol propellants, burning of fossil fuels and methane
C ammonia gas, water vapour and carbon monoxide
D carbon monoxide, carbon dioxide and nitrous oxide

6 Global warming is predicted to cause:
A skin cancer
B flooding in coastal areas
C defoliation of plant foliage
D cyanide poisoning

7 a) 'The more industrialised countries are more responsible for global warming of the Earth.' Explain to a public gathering how this statement can be justified.
b) Explain how the following can minimise the effects of global warming:
(i) afforestation
(ii) hydro generation of electricity
(iii) increasing the cost of fossil fuels.

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8 Fill in the best word or words in each of the parentheses that will complete the sentences on the ozone layer in the stratosphere and the global warming phenomena.

a) The relative molecular mass of carbon dioxide is 44 and that of the halon CBr_2ClF is (i) [... *226.5 ...146.5 ... 226*]. As gases, CBr_2ClF (ii) [... *is lighter ... is heavier ... has the same density*] than CO_2 and therefore displaces air (oxygen) away from fire better than CO_2. It is used in fire extinguishers but contributes to ozone layer depletion because it contains the atom (iii) [... *carbon, C ... bromine, Br ... Chlorine, Cl*]. (Relative molecular mass of C = *14*, Br = *80*, Cl = *36.5*, F = *19*.)

b) The following are greenhouse gases: (i) [... *oxygen, O_2 ... ozone, O_3 ... carbon dioxide, CO_2 ... nitrogen(I) oxide, N_2O .... methane, CH_4*]. The greenhouse gases are produced by (ii) [... *burning of fossil fuels ... decay of refuse or plant garbage ... hydroelectric plant*]. Examples of fossil fuels are (iii) [... *coal ... petrol ... kerosene*]. When the greenhouse gases are produced through human activities they are trapped in the Earth's atmosphere and radiate (iv) [... *ultraviolet radiation ... infrared radiation*] back to the Earth's surface to cause (v) [... *global warming ... ozone hole ... acid rain*] in the atmosphere. Effects of global warming is/are (vi) [... *climate change ... afforestation ... deforestation ... unexpected cyclones and hurricanes*].

9 a) List three sources in your country which contribute to global warming.

b) Explain how one source can contribute to global warming.

10 a) Explain how the ozone layer in the atmosphere is depleted.

b) State two effects that the depletion of the ozone layer can have on plant or animal life.

11 a) Make a labelled sketch of the five main layers of gas that make up the Earth's atmosphere.

b) Indicate in the sketch the layer in which the ozone layer is located.

c) Explain briefly in which layer of the atmosphere:
(i) air travel is most desirable
(ii) atmospheric pressure is the highest.

12 a) State two human activities that can result in acid rain.

b) Explain two possible manifestations of the effect of acid rain.

c) State two ways by which acid rain can be minimised.

13 What is global warming? Discuss its causes and environmental effects.

14 Acid rain, ozone layer depletion and global warming are environmental effects that are created by human activities. The following human activities can contribute to one or more of these three environmental effects: industrialisation and agriculture, defence or transportation.

a) For each environmental effect state the human activity that can cause it.

b) Explain how each human activity creates the environmental effect.

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3 Tectonic movements

Learning objectives

After studying this unit, you should be able to:

1 identify the layers of the Earth
2 describe the significance of plate tectonics
3 explain how plate tectonics cause Earth tremors, earthquakes, volcanoes and tsunamis
4 give examples of recent land formations and submerging lands.

Background information

The Earth surfaces are undergoing changes. This is the result of Earth tremors, earthquakes, volcanic eruptions and other factors, such as flooding and erosions. New lands are being formed as a result of tectonic movement. It is a field of study that is not only interesting but also relevant to us.

The layers of the Earth

The Earth is a spherical body made up of the following layers (Figure 1.184):

- crust
- mantle
- outer core
- inner core.

The Earth's crust

The Earth's crust is made up of layers of rocks which extend 25 miles (40 km) down. The crust consists of rocks of varying densities which are classified under sedimentary, metamorphic and igneous rocks. The

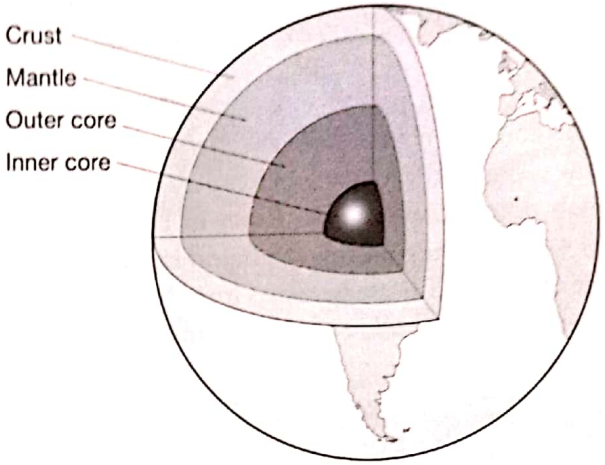


Fig 1.184 Section through the Earth.

Earth's crust interacts with the atmosphere and water bodies. It has organic and inorganic layers.

The crust is also divided into two regions:

- continental region
- ocean crust.

The continental Earth crust is about 25 miles (40 km) thick. The ocean crust is about 5 miles (8 km) thick. The boundary between the Earth crust and the mantle is defined by the Mohorovicic Seismic discontinuity.

Mantle

The upper mantle consists of silicate minerals in which dark green olivine dominates. It also has black pyroxene, iron silicate and calcium aluminium silicate.

The temperature of the mantle is very high and increases with depth to 2700 °F or 1500 °C. At this high temperature the rocks in the form of peridotite starts to melt. There is a low velocity layer and balsalt magmas that erupt through oceanic volcanoes.

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Table 1.46 Features of the layers of the Earth

Layer of the Earth	Thickness/km	Density/cm^3	Temperature °C	Description
crust	5–50	2.9	20–500	thickness varies
mantle	2900	3.6	500–2000	partly liquid, partly solid, hot and always moving
upper core	2270	3.6	3000	molten iron and nickel
inner core	1300 (radius)	9.5	4000	solid iron and nickel

A further increase in depth in the mantle leads to rapidly increasing temperatures which melt the minerals. The inner mantle, which is referred to as the **asthenosphere** or weak layer, in its plastic state is different from the upper rigid mantle and crust called the **lithosphere**.

Core

In the core there are significant physical and chemical changes due to the increase in temperature and pressure which occur across the boundary of the core and the mantle. In this region solid to liquid is the order of the state of matter. Silicate becomes iron. Nickel in the core is iron rich and an alloy of nickel iron.

Plate tectonics

The lithosphere is a region in the layers of the Earth which is fragmented into seven pieces called **plates**. The plates can be likened to a gourd that has cracked in several areas. These seven plates of the lithosphere move relative to each other. They slide on the underlying asthenosphere. The study of the manner in which the plates move is called **plate tectonics**.

In 1915 a German geologist called Alfred Wegener suggested that about 200 million years ago all the continents were joined, like pieces in a jigsaw. For example, Africa and South America can fit together, Australia and Antarctica can form a unit, and South Africa can fit into the dent in Antarctica. This hypothesis was called the theory of **continental drift**. It is supported by evidence of:

- similar rocks in Australia and Antarctica
- fossils of similar ancient ferns found in both Africa and Brazil
- fossils of crocodile-like animals found in both Brazil and Africa.

Wegener's hypothesis met widespread opposition, because he could not explain *how* the continents had moved. However, after his death, other evidence came to light that seemed to support his ideas – notably the fact that the sea bed is actually spreading.

Finally, in 1965, the Canadian geophysicist John Tuzo Wilson formulated the theory of plate tectonics. This says that the Earth's outermost layer, or crust, can be thought of as a jigsaw of rigid major and minor plates of solid rock up to 100 km thick, moving relative to each other on top of the semi-liquid mantle of rock beneath. The plates move around slowly as a result of convection currents in the mantle, at speeds of 1–10 cm per year (Figure 1.185). The plates in different parts of the world may be slipping past each other, moving towards each other or moving away from each other.

This small movement is still enough to cause earthquakes and volcanoes where the plates are colliding or moving apart. Large **earthquakes** occur where the plates slip a few metres past each other. The boundaries of the plates coincide with the world's earthquake zones.

The colliding plates are also responsible for the formation of mountains, such as the Himalayas. A large amount of heat and pressure exists in the core of the Earth. Rocks under heat and pressure can bend gradually (over millions of years) without breaking. When this happens the result is called **folds**. Folds form a landscape referred to as **anticlines** (mountains) and **synclines** (valleys).

When the plates separate or move apart, lava flows from the mantle to fill the space. The lava cools to form mid-ocean ridges. **Volcanoes** appear where molten rock from beneath the crust rises to the surface through the joints between the plates. Most of the world's volcanoes occurs within the ridges.

The effects of plate tectonics

The movement of the plates causes:

- Earth tremors
- earthquakes
- volcanic eruptions/tsunamis.

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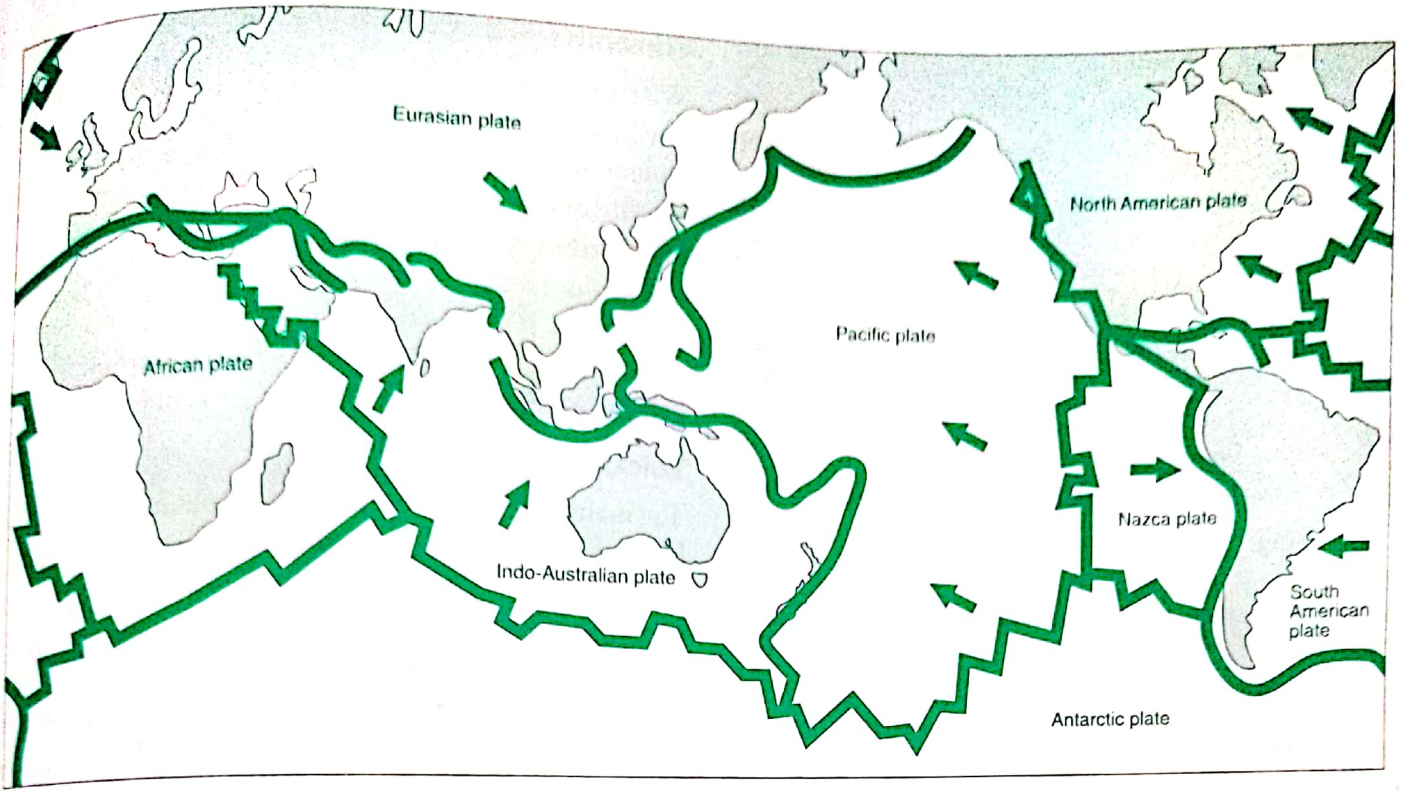


Fig 1.185 The Earth's plates and how they are moving.

Earth tremors

The sliding plates may slip and jerk in their movements. Under such jerks a wave motion is set in place in certain regions of the Earth, producing vibrations accompanied by noise or in some cases sound which cannot be perceived by the human ear. Tremors are recorded on the Richter scale by a wavy recording on the Richter register.

Earth tremors when violent, especially when they occur along faults, are referred to as earthquakes. They vary in intensity and duration but in most cases last between a few seconds and about 3 minutes.

Earthquakes

Earthquakes are a trembling or shaking of the Earth. Earthquakes result in landsliding damage to installations, buildings and bridges. Earthquakes cause ridging of the sea bed and violent acceleration of the ocean waves causing enourmous damage to ocean vessels, on the sea, to coastal communities and massive destruction to life and property (Figure 1.187).

An earthquake is a natural phenomenon that cannot be eradicated (there is no record of its eradication). Efforts can, however, be put in place to mitigate the effects of earthquakes. These preventive measures include mapping out earthquake prone zones and educating people to avoid building in the zones (Figure 1.188).

Buildings can be constructed so they are not vulnerable to earthquakes, for example, tower-shaped with rubber or plastic roofs. Rocks and flexible steel should be used to build houses. In Japan houses rest

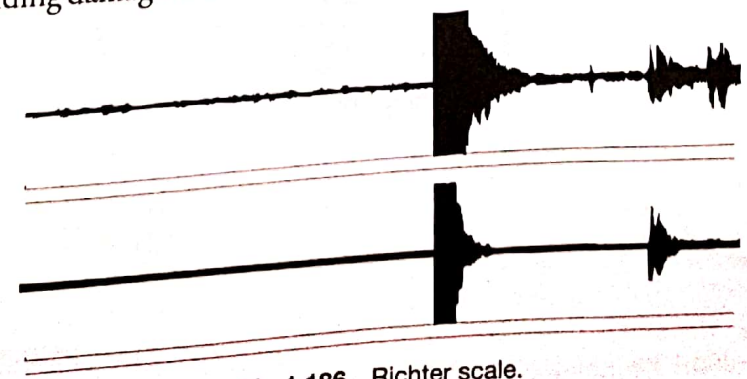


Fig 1.186 Richter scale.

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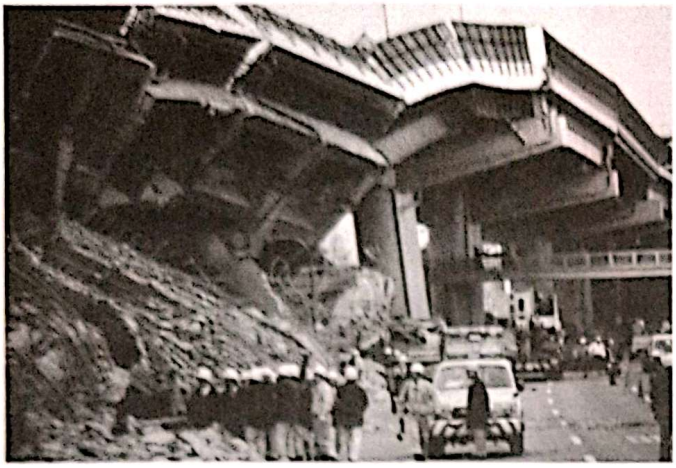


Fig 1.187 Destruction from earthquakes.

on rollers to keep the houses from falling during earthquakes.

There should be areas in communities for people to seek shelter in case an earthquake strikes. Earthquake warning devices must be built in communities to warn against earthquakes.

Tsunamis (tidal waves)

When an earthquake occurs in the ocean bed it sets up a wild vibration which accelerates the sea waves. Such violent sea tides are referred to as **tsunamis** and can travel distances destroying land masses, buildings and installations along their path.

Serious tsunamis cause flooding by pushing fresh water back from entering the sea. Some tsunamis are the result of volcanic eruption which occurs on the sea bed.

Volcanoes

The mantle of the Earth is a semi-liquid magma which is like a thick porridge or a paste. The paste-like substance in the mantle can flow, it is extremely hot and in parts it is molten. The thick molten rock is also called **magma** and contains dissolved gases.

The pressure from the surrounding rocks keeps the molten magma fairly solid. Sometimes the enormous pressure from the surroundings forces the magma to flow through faults – weaker parts of the Earth's crust. When this happens the volcano erupts. The eruption is similar to the spillage we find when we prepare porridge or groundnut puree for soup.

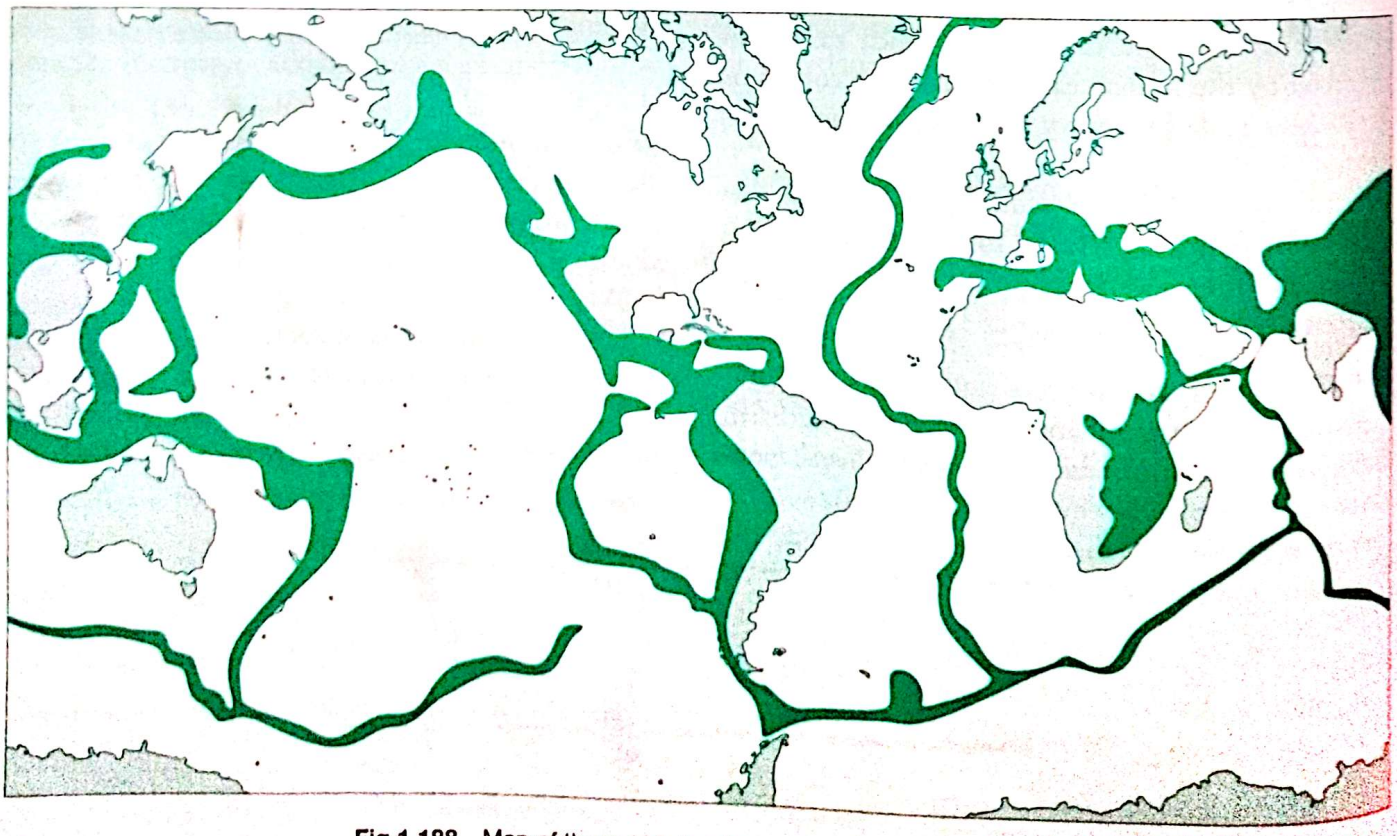


Fig 1.188 Map of the world showing earthquake prone areas.

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Fig 1.189 An erupting volcano.

A volcano is a magma being squeezed to the surface of the Earth's crust. It is similar to when you shake a bottle of Coca Cola or Malta Guinness and place a drinking straw into it. Pressure builds up and oozes out with violent and rapid movement. It is an eruption. The magma erupts from vents and flows around, cakes up and creates hills or even mountains.

There are over 500 active volcanoes in the world. Cameroon has an active volcano. When magma reaches the surface of the Earth it is called **lava**. It is about 1000°C but cools to become very hard rock.

Rocks that form from molten lava are called **igneous** rocks. The word 'igneous' means formed from fire. Igneous rocks contain crystals. Crystals are solids of definite shape with straight, sharp edges as found in sugar and salt crystals.

There are two types of igneous rocks:

- those formed from volcanic eruption
- those formed from plutonic rocks.

Volcanic igneous rocks were formed from lava that flowed from volcanic eruptions on to the surface of the Earth. When the lava cools crystalline igneous rocks are formed. Basalt was formed in this way through volcanic processes.

Plutonic rocks are formed from magma that flowed but did not reach the surface of the Earth. The surrounding rocks prevented rapid cooling and so large crystals had time to grow. Granite is a typical example of plutonic rock. Such rocks contain a lot of minerals. What types of rocks are found in your area? Do the rocks suggest the flow of magma or the cooling of lava?

Land formations and submerging lands

As a result of ongoing tectonic movements of the Earth's crust, the crust is undergoing transformation. When two plates move, one moving over the other, this results in the oceanic plate submerging under the continental plate.

A typical example in the Pacific ocean is the South American plate that moves towards the oceanic Nazca plate. By this process new lands are formed and mountains are formed through folding. This occurs when two continental plates move towards each other. New islands have been formed near Japan and other parts of the world in this way.

ACTIVITY 1 Research land formations and submerging lands

1 Use the internet or scientific journals to identify and find out about some recent land formations and submerging lands.

2 Write an illustrated report on your findings and discuss with the class.

Self check

1 Draw the Earth and show the following strata:
a) core **b)** mantle **c)** crust.

2 Compare the substance in the core of the Earth with that of the mantle.

3 **a)** What is meant by tectonic movement?
b) How does tectonic movement influence the physical features of the Earth?

4 Describe the formation of:
a) volcanoes
b) earthquakes.

5 **a)** Which rocks are termed plutonic?
b) Describe how plutonic rocks are formed.

6 What is meant by the following terms:
a) continental drift
b) tsunami.

7 How does tectonic movement influence flooding?

8 **a)** In which strata of the Earth is crystallisation of rocks dominant?
b) How does crystallisation promote formation of quartz?

9 New islands are formed as a result of tectonic movement. Describe how this happens.

10 What is the heat in the core of the Earth used for in the field of energy production?

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4 Infections and diseases

Learning objectives

After studying this unit, you should be able to:

1 describe the causes of diseases
2 describe the modes of transmission, symptoms and modes of control of common diseases.

Background information

Microorganisms abound in our environments especially those environments that are characterised by poor sanitation. The environments include the atmosphere surrounding us, water bodies and the soil in which crops are cultivated. Whilst some of the microorganisms are beneficial, others are harmful. The harmful microorganisms include those that cause various kinds of diseases to humans, crop plants and livestock.

Disease-causing microorganisms are technically referred to as **pathogens**. Humans, plants and livestock become diseased when they are infected by pathogens transmitted from diseased living organisms. The modes of transmission of pathogens depend on their nature and life cycles. Diseases may also be caused by non-living factors. These include extreme environmental conditions, stress, malnutrition and poisons.

Diseases are generally detrimental to the health and well-being of all living organisms. They also cause considerable economic losses to humans and nations. For these reasons, scientists have done a lot of studies and research into diseases and developed credible methods of preventing and controlling them.

Diseases

A **disease** is any disorder that interferes with normal functioning of the body of an organism in a negative way.

Diseases can be **pathogenic** (caused by pathogens) or **non-pathogenic** (caused by nutritional or metabolic disorders). Pathogenic diseases are caused by micro-organisms – bacteria, fungi, viruses and protozoa. Pathogenic diseases can be classified into the following groups:

- **Infectious diseases** – diseases that are easily transmitted from one organism to another through a vector (an insect) or a medium, such as air, water and food, e.g. cholera and anthrax.
- **Contagious diseases** – diseases transmitted through contact with an organism suffering from the disease; mainly viral diseases, e.g. mumps and swine fever.
- **Zoonotic diseases** – diseases that affect both livestock and humans, e.g. anthrax and rabies.
- **Epizootic diseases** – diseases that are prevalent only temporarily, e.g. tick-borne diseases, such as redwater and heartwater in livestock.
- **Endemic diseases** – diseases that are prevalent in particular geographic regions on a regular basis, e.g. trypanosomiasis.

Bacterial diseases

Bacteria (singular: bacterium) are microorganisms visible only under a microscope. They are the most versatile group of pathogens, but they are readily controlled by strict hygiene, vaccination and the use of antibiotics. Diseases caused by bacteria include tuberculosis, cholera,

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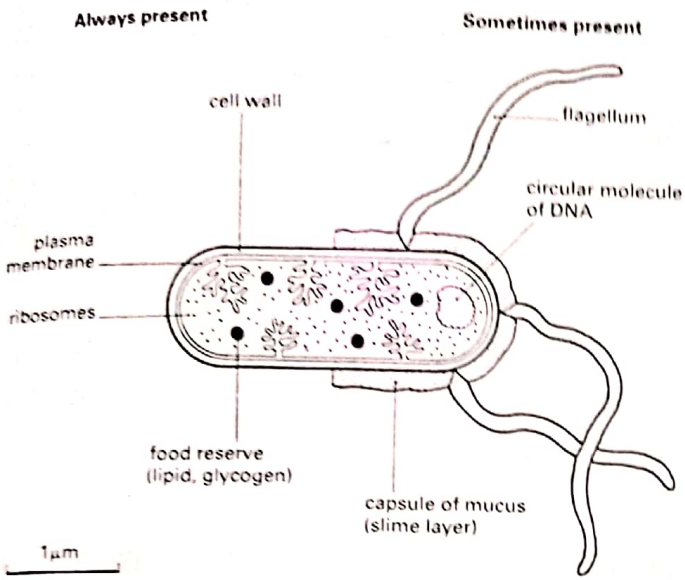


Fig 1.190 A bacterium.

tetanus in humans; anthrax, brucellosis and foot rot in livestock.

Bacteria live almost everywhere – in the air, water, food, soil and the bodies of animals and plants. In favourable conditions of sufficient moisture, warmth and food, they reproduce rapidly. In adverse conditions, such as heat and drought, many bacteria survive by encysting, that is, by developing a thick coat.

Bacteria have various shapes – round (coccus), rod (bacillus) and spiral. A rod-shaped type is shown in Figure 1.190.

Disease-causing bacteria are parasites. They feed on their host. Their excretory substances, which are often poisonous and the main cause of the disease, are called **toxins**.

Protozoan diseases

Protozoa (singular: protozoan) are single-celled microscopic organisms. The diseases they cause, such as malaria and amoebic dysentery in humans, trypanosomiasis (Figure 1.191) in both humans and livestock, and coccidiosis and redwater in livestock, are often accompanied by high fever, loss of appetite,



Fig 1.191 A trypanosome (causes sleeping sickness).

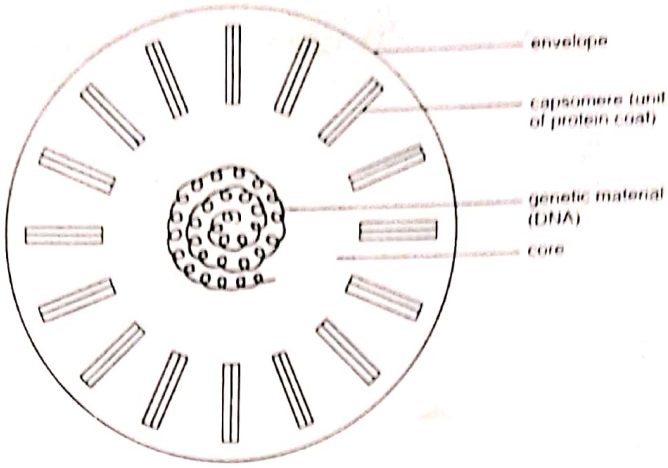


Fig 1.192 A virus particle.

emaciation (loss of weight) and death within 2–3 weeks of attack.

Viral diseases

Viruses (singular: virus) are ultra-microscopic organisms (Figure 1.192). They can only be seen under an electron microscope. They are so tiny that if they were to be lined up in a row across the page of an exercise book, there would be over 2 million of them. They consist of two parts: a protein coat and nucleic acid (either DNA or RNA).

Viruses are parasites. The viral DNA or RNA is injected into the living cell and it 'takes over'. The host's chemicals are used to produce more and more new viruses. Eventually, the cell bursts and the new viruses attack other host cells. This explains why they are so harmful.

Viral diseases are easily transmitted but they cannot easily be prevented or controlled. Many serious human diseases, such as measles, poliomyelitis, yellow fever and rabies, are caused by viruses. Livestock diseases include rinderpest, foot and mouth disease, swine fever and Newcastle disease.

Fungal diseases

Fungi (singular: fungus) are very tiny lower organisms whose parasitic forms causes diseases, such as athletes foot, ringworm and aspergillosis in fowl.

Rickettsial diseases

Rickettsiae (singular: rickettsia) are microorganisms which were once classified as viruses, but are now considered as a special kind of bacterium because they

Richmond

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fall mid-way in characteristic features between bacteria and viruses. They are, however, smaller in size than bacteria but, like viruses, they reproduce only in living cells.

Rickettsiae live primarily in the cells of livestock parasites, such as ticks and mites, and cause livestock diseases, such as heartwater and Q fever. Symptoms of rickettsial diseases include high fever, body muscle convulsion, rashes and sudden death. They are controlled effectively with antibiotics, dipping and deticking to control ticks, and the destruction of seriously affected animals.

Non-infectious diseases

A non-infectious disease is non-pathogenic, that is, one that is caused by the absence or deficiency of something in the body. It is often linked to nutrition, e.g. deficiency diseases.

Generally, non-pathogenic diseases are caused by poor animal husbandry and management practices. The predisposing factors to such diseases include those discussed below.

Poor nutrition

Poor nutrition refers to the feeding of unbalanced diets to animals and inadequate or over-feeding. This makes it difficult for the animals to carry out their normal physiological function due to the effects of nutrient deficiency diseases they may suffer from. Examples of diseases caused by poor nutrition are crazy chick disease in poultry, hypocalceamia (milk fever) in dairy cattle, pregnancy toxaemia in sheep and goats, and bloat in ruminants.

In humans poor nutrition causes non-pathogenic diseases, such as kwashiorkor, rickets and beri-beri.

Genetic disorders

These cause non-pathogenic diseases that are inheritable from parents to offspring. They include sickle cell anaemia, haemophilia, colour blindness, piglet anaemia and Huntington disease in humans.

Stress

This refers to a group of factors that produce great strain in both animals and humans. In farm animals extreme climatic conditions, beating the animals, transportation, over-crowding, castration and debeaking are some stress factors. They cause abnormal functioning of the systems of the animals, resulting in non-pathogenic diseases, such as porcine stress syndrome (PSS) in pigs. In humans stress causes depression and ill health.

Poor sanitation

Poor sanitation in and around animal houses is a predisposing factor to both non-pathogenic and pathogenic diseases of farm animals.

Poisons (or toxins)

Poisonous and toxic substances, such as substances injected into animals during snake bites, cause a degeneration of the systems of the animals. This results in serious ill health and often death.

Modes of transmission, symptoms and control of diseases

Disease infection refers to the entry of disease-causing organisms (pathogens) into healthy animals resulting in a disturbance of physiological functions and creating a disease condition in the infected animal(s).

Disease pathogens are transmitted through different modes depending on the type of disease and nature of pathogen. Below are descriptions of the modes of disease transmission for selected groups of diseases.

- **Communicable diseases** – diseases are communicable if they are easily transmissible between people, mainly through direct and indirect contact. Most contagious and infectious diseases are communicable diseases spread by infected droplets exhaled or coughed into the air. Examples are anthrax, contagious bovine pleuro-pneumonia (CBPP), tuberculosis (TB) and African swine fever. The six childhood killer diseases are also communicable.
- **Zoonotic diseases** – these are infectious diseases of animals that can be transmitted to humans. Examples are anthrax, rabies, brucellosis, salmonellosis and tuberculosis. Zoonotic diseases fall under different groups of diseases. They therefore have several different modes of transmission including contact, food contamination and inhalation of pathogens in the air.
- **Air-borne diseases** – these are diseases caused by pathogens that are in the form of particles, droplets or dust that easily saturate the surrounding air and are also transmitted by moving air. Transmission

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is effective in poorly ventilated and over-crowded environments. Most respiratory diseases are air borne. They include tuberculosis, chronic respiratory diseases (CRD) in poultry and contagious bovine pleuro-pneumonia in ruminants. Examples of air-borne diseases of humans are measles, smallpox, common cold, whooping cough and influenza.

- **Water-related diseases** – the pathogens of these diseases are transmitted by water. Drinking water contaminated by the pathogen is the usual way to get infected. Guinea worm disease is a water-related disease. These diseases are very common in Ghana and some other West African countries. Other examples are cholera, schistosomiasis (bilharzia), poliomyelitis and infective hepatitis.
- **Insect-borne (vector) diseases** – some insect pests, called **vectors**, carry pathogens which transmit diseases when they bite animals or humans. The tsetse fly, which transmits the trypanosomiasis disease of livestock, is one example of such vectors. Other examples are ticks, which transmit heartwater and redwater diseases of farm animals, mosquitoes, which transmit malaria parasites through their bites and the simulium fly (black fly), which transmits onchocerchiasis (river blindness).
- **Food contamination** – food and feed contaminated with pathogens transmit diseases to humans and animals, respectively, through the eating of such foods and feeds. Examples of food contaminated diseases are African swine fever and Aspergillosis.
- **Sexually transmitted diseases** – sexual intercourse and mating in humans and animals, respectively, transmit these diseases from the sick to the healthy. AIDS, gonorrhoea and syphillis are major sexually transmitted diseases of humans. Brucellosis is an example of this class of diseases among farm animals.

The symptoms and control measures of the diseases described under the different modes of transmission are outlined in Tables 1.47, 1.48 and 1.49.

Table 1.47 Details of some animal diseases

Disease	Pathogen	Animals affected	Transmission	Symptoms	Prevention and control
African swine fever	virus	pigs (swine)	direct contact with contaminated food, water and equipment; wild pigs are carriers	high fever, anorexia; coughing and vomiting; diarrhoea; foul-smelling discharges from the nose and eyes; paralysis of the hindquarters	good hygiene; quarantine; breeding for resistance; isolation and destruction of affected pigs
rabies	virus	cattle, dogs, cats, humans	through the saliva of the infected animal	profuse salivation; paralysis and dumbness; voice changes; refuses water and is sometimes frightened by the sight of water; hiding in dark corners; furious without provocation	quarantine; vaccination; destruction of animal in acute cases
blue tongue	virus	sheep	by midges	intensive fever, loss of appetite; nasal discharge; mouth ulcers; lameness; coughing	seek veterinary assistance; slaughter infected animals
tuberculosis	bacterium: *Mycobacterium tuberculosis*	all livestock and humans	inhalations of bacteria, contact and food	coughing; laboured breathing; chronic illness; loss of coat colour, diarrhoea; discharges from mouth and nose; death	seek veterinary assistance; slaughter infected animals

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Table 1.47 Details of some animal diseases *(continued)*

Disease	Pathogen	Animals affected	Transmission	Symptoms	Prevention and control
heartwater	rickettsia: *Cowdria ruminantium*	cattle, sheep and goats	ticks (*Amblyomma* spp.)	intense fever, walking in circles; paralysis; pericarditis; protruding tongue; galloping movement; collapse and death	action against ticks; anti-heartwater serum vaccination; use of antibiotics
redwater (babersiosis)	protozoon *Babersia spp.*	cattle, sheep, pigs, dogs	ticks	loss of appetite; red urine due to breakdown of red blood cells; stiff walking; pale and yellowish mucus membrane; abortion in pregnant animals; salivation; anorexia; death	use antibiotics and sulpha drugs; action against ticks; vaccination; strict sanitation
foot rot	bacterium: *Fusiformis nodosus*	sheep, goats, cattle, pigs, donkeys	open wound; contaminated water contact	swollen foot; acute lameness; sore hooves; anorexia; sudden high body temperature; cracked and ulcerated interdigital spaces; inability to rise	use of dry bedding in pens; use of antibiotics on sores; good sanitation; provision of copper sulphate formalin footbath; intravenous injections of recommended sulpha drugs; isolation
aspergillosis: (brooder pneumonia)	fungus: *Aspergillus fumigatus*	poultry, especially fowl chicks during brooding	contaminated wet litter; mouldy feeds, especially groundnut cake	difficulty in breathing; dull comb and skin; high chick mortality rate	use clean feed, water and equipment; culling of sick birds; use of antibiotics in feed and water; spray litter with phenyl-mercuric chloride solution
tetanus (lockjaw)	bacterium: *Clostridium tetani*	most livestock and humans	wounds; contaminated deep cut	muscle spasm; limb stiffening; jaws cannot move; profuse sweating; increased insensitivy of skin; careful chewing and swallowing; death	prevent wound infections through anti-tetanus serum immunisation; give glucose saline; give tranquillisers to relax muscles

Table 1.48 Diseases caused by bacteria

Disease, bacterium and method of spread	Symptoms and course of disease	Treatment and control
diphtheria (bacillus) *Corynebacterium diphtheria* air borne	Incubation period 2–4 days. Bacteria grow on mucous membranes of respiratory tract, releasing a powerful toxin. Slight fever and sore throat are followed by severe damage to heart, nerve cells and adrenal glands.	Treatment: • injection of antitoxin • antibiotics, e.g. penicillin and erythromycin. Control: mass immunisation with diphtheria toxoid (toxin which has been treated so that it is no longer harmful).
typhoid and paratyphoid (bacilli) *Salmonella typhi* and *S. paratyphi* water borne and food borne	Incubation period 6–7 days. Mild fever and slight abdominal pains with constipation, followed by step-like increase in fever level, increasing pain and diarrhoea. Ulceration and rupture of the intestine may occur.	Treatment: antibiotics, e.g. chloramphenicol and ampicillin (semi-synthetic penicillin). Control: • purification of water supplies • safe disposal of sewage • pasteurisation of milk • vaccination with killed bacteria.

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Table 1.48 Diseases caused by bacteria *(continued)*

Disease, bacterium and method of spread	Symptoms and course of disease	Treatment and control
whooping cough (bacillus) *Bordetella pertussis* air borne	Occurs mainly in young children. Incubation period 2 weeks. Severe coughing bouts, with cough followed by 'whoop' sound as air is inspired through narrowed air passages.	Treatment: antibiotics. Control: vaccination with killed bacteria.
bubonic plague (bacillus) *Pasteurella pestis* spread by rat flea bite	High fever. Swelling of lymph nodes in groin and armpits to form buboes. Capillary haemorrhages give dark appearance to skin, hence the name 'black death'.	Treatment: antibiotics, such as streptomycin. Control: eradication of rats and storage of grain, etc. in rat proof containers.
yaws (spirochaete) *Trepoanoma pertenue* spread by direct contact with sores	Occurs mainly in children under 15. Open sores (lesions) spread over the body surface. Bones also affected in severe cases.	Treatment: antibiotics, such as penicillin. Control: improved standards of hygiene and prevention of over-crowding.
tetanus (lockjaw) (bacillus) *Clostridium tetani* bacteria present in soil, dust or animal faeces contaminate skin wounds	Toxins produced by bacteria cause muscular spasms (strong contractions), first in the region of the mouth and neck, then throughout the body. Eventually, convulsions may be so severe and frequent that the patient dies of exhaustion or lack of oxygen. Commonest in war (infected wounds) and newborn babies (infected stump of umbilical cord).	Treatment: • injection of antitoxin from horses • injection of muscle relaxing drugs • antibiotics, such as penicillin. Control: immunisation with tetanus toxoid.
pneumonia (lobar) (coccus) *Diplococcus pneumoniae* air borne	Short incubation period, followed by coughing, fever and chest pain. Fluid builds up in lungs. Bacteria often present in throat, but become active and invade the lungs when the patient is weakened by other illness. Several types of pneumonia exist, including some caused by viruses.	Treatment: antibiotics, such as penicillin and sulphonamides. Control: good ventilation and prevention of over-crowding.
meningitis (spotted fever) (coccus) *Neisseria meningitidis* air borne	Bacteria multiply in mucous membranes of the nose and throat, producing a sore throat, then enter the bloodstream and infect brain coverings (meninges). High fever, vomiting and severe headaches, with general body rash.	Treatment: antibiotics, such as penicillin and sulphonamides. Control: prevention of over-crowding, especially in sleeping accommodation.
tuberculosis (TB) (bacillus) *Mycobacterium tuberculosis* air borne, occasionally via infected cow's milk	Disease may show itself many years after first infection. Tubercle bacilli may affect many organs, but pulmonary (lung) TB is the most common. General weight loss and cough, sometimes with sputum containing blood; slight afternoon fever.	Treatment: antibiotics, such as streptomycin. Control: • detection by mass radiography • eradication of cattle TB • vaccination with BCG (Bacille Calmette Guerin) • pasteurisation of milk.
leprosy (bacillus) *Mycobacterium leprae* air borne, occasionally by direct contact over long periods	Incubation period of many months or even years. Two forms: • nodular, with thickened areas of skin • anaesthetic in which the peripheral nerves are destroyed.	Treatment: drugs, such as streptomycin, dapone, sulphone. Control: segregation and isolation; now less common than in previous centuries.
cholera (vibrio) *Vibrio cholerae* water borne	Bacteria release powerful toxin, causing inflammation of the gut and severe diarrhoea ('rice water'). The resulting loss of water and mineral salts may lead to death.	Treatment: • injection of saline solution to replace water and salts • drugs, such as tetracycline, chloramphenicol and sulphadiazine.

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Table 1.49 Diseases caused by viruses

Disease and method of spread	Symptoms and course of disease	Treatment and control
Measles air borne	Occurs mainly in young children. Incubation period of 2 weeks, followed by sore throat, runny nose, watery eyes, cough and fever. Small, white spots (Koplik's spots) appear inside mouth on wall of cheek. Two days later, rash appears at the hairline, in the neck and behind the ears, spreading over rest of the body. If no complications, patient recovers completely 1 week later, but virus can damage heart muscle, kidneys or brain and secondary infections by bacteria may cause pneumonia, etc.	Treatment: injection of gamma globulin a few days after exposure. Control: • live, attenuated vaccine • isolation of patient and avoidance of over-crowding in schools.
rubella (German measles) air borne	Occurs mainly in older children and young adults. Incubation period of 2 weeks, followed by slight fever and body rash which disappears after 3 days. Complications rare except in women during the first four months of pregnancy, when there is a 20 per cent chance of blindness, deafness or other serious defects in the baby.	Treatment: • mild analgesics, such as aspirin and paracetamol • for pregnant women, injection of gamma globulin within 8 days of exposure. Control: vaccination of girls aged 11–14 with live attenuated virus.
mumps air borne or spread by contact with infected saliva	Occurs mainly in children. Incubation period of 2–3 weeks, followed by fever and swelling of the salivary glands on one or both sides,lasting about 10 days. Other organs may be affected, including testes, ovaries and pancreas. Inflammation of the testes in a male after puberty may cause sterility.	Treatment: aspirin, etc. to relieve symptoms. Control: a vaccine has been developed, but as yet availability is limited.
chicken pox air borne	Occurs mainly in children and young adults. Incubation period 2 weeks, followed by fever, headache, sore throat and rash (typically on chest, spreading over body). Blister-like spots are very itchy; if scratched may become infected by secondary bacteria and leave permanent scars. Virus may migrate up sensory nerve fibres and lie dormant for years, becoming active again when immunity weakens to produce shingles (a painful condition affecting the skin supplied by the nerves concerned).	Treatment: no drugs effective against virus; antibiotics used to treat secondary bacterial infections.
common cold air borne	Nasal and bronchial irritation, resulting in sneezing and coughing.	Treatment: aspirin, etc. Control: colds can be caused by many different viruses so vaccine production is impracticable. People who have recovered from a cold caused by one virus are not immune to colds caused by other viruses.
influenza (sweating sickness) air borne	Incubation period 1–3 days. Sudden fever with headache, sore throat and muscular aching. Recovery within 1 week, but after-effects such as tiredness and depression (especially in older people) may last well over a month. Secondary infection of the lung tissue by bacteria, leading to pneumonia may occur in some cases.	Treatment: • analgesics • antibiotics to prevent secondary infections. Control: vaccination with inactivated virus may give immunity for 1–2 years.

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Table 1.49 Diseases caused by viruses *(continued)*

Disease and method of spread	Symptoms and course of disease	Treatment and control
rabies contracted from bite of rabid animal (dog, cat, bat, etc.)	Incubation period 7–21 days, followed within a few days by convulsions and inability to swallow. Accumulated saliva causes 'foaming at the mouth'. Usually fatal.	Treatment: • wash and disinfect wound • inject horse serum containing antibodies near wound • inject vaccine. Control: • strict import and quarantine controls on animals entering rabies free areas • vaccination of domestic dogs in other areas.
poliomyelitis (infantile paralysis) air borne, food borne or water borne, also contagious	Incubation period 7–21 days, followed by fever, headache and feeling of stiffness in neck and other muscles, causing paralysis and muscle wasting. If breathing muscles are paralysed a respirator ('iron lung') may be needed. Many people have a very mild form of the disease which they do not notice but which makes them immune. Most cases of paralysis occur in children 4–12 years but adults may also be affected.	Treatment: no known drug or chemical treatment. Control: vaccination with formaldehyde treated virus (Salk vaccine) or mutated virus (Sabine vaccine) taken orally.
infective hepatitis water borne, also contagious	Incubation period 15–40 days, followed by loss of appetite, vomiting and jaundice – yellow colour of sclerotic or 'eye white' caused by bile pigments and showing liver disorder. In pale-skinned people the yellow colour may affect the whole complexion in addition to the sclerotic	Treatment: injection of human gamma globulin soon after exposure. Control: boiling of drinking water and attention to hygiene; injection of gamma globulin usually too expensive for prophylactic (preventative) use.
yellow fever spread by bite from *Aedes* mosquito	Incubation period 2–4 days, followed by high fever, severe headaches and general body pains. Three days later, symptoms include swollen eyes, bleeding gums, vomiting and jaundice. Sever liver damage is common. The disease is endemic in Africa and South and Central America. Monkeys act as a reservoir.	Control: • removal of mosquito breeding places • spraying insecticides to kill adult mosquitoes • sleeping under mosquito net • vaccination with mutated virus, effective and long lasting (10 years).
dengue fever spread by bite from *Aedes* mosquito	High fever, with severe pain in joints. Fever subsides and then returns with a typical rash. Recovery after about 5 days.	Control: anti-mosquito measures as for yellow fever.

ACTIVITY 1 Causes, symptoms and mode of transmission of some common diseases

1 *Work in groups* to discuss the causes, symptoms and mode of transmission of the following common diseases:
   a) tuberculosis
   b) malaria
   c) Newcastle disease.
2 Discuss how these diseases can be prevented or controlled

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Self check

For questions 1 to 10, choose the letter that refers to the correct option.

1 Which of the following diseases is non-pathogenic?
A coccidiosis **B** anthrax
C haemophilia **D** rabies

2 Vaccination and the use of antibiotics are effective ways of controlling diseases caused by:
A fungi **B** viruses
C nematodes **D** bacteria

3 Which of the following diseases is nutrition related?
A heartwater disease **B** rinderpest
C bloat **D** anthrax

4 Which of these diseases is likely to make a child a cripple?
A malaria **B** cholera
C tuberculosis **D** poliomyelitis

5 The common name for onchocerciasis is:
A bilharzia **B** river blindness
C dysentery **D** sleeping sickness

6 Blood in urine is a major symptom of:
A schistosomiasis **B** onchocerciasis
C elephantiasis **D** ascariasis

7 Which of the following diseases is not caused by protozoa?
A trypanosomiasis **B** redwater
C rinderpest **D** coccidiosis

8 Diseases that affect both humans and livestock are classified as:
A communicable diseases **B** endemic diseases
C zoonotic diseases **D** epizootic diseases

9 The body's ability to resist disease infection by producing antibodies is referred to as:
A quarantine **B** immunity
C tolerance **D** hybrid vigour

10 Which of the following symptoms is that of schistosomiasis?
A chest pains **B** constipation
C dysentery **D** cataracts

11 **a)** Define the term 'disease'.
b) Distinguish between pathogenic and non-pathogenic diseases.
c) State three symptoms of African swine fever.

12 **a)** Name the pathogen that causes Guinea worm disease.
b) Describe how the disease infects humans.
c) Outline the effects of the disease on society.
d) State three ways of controlling the disease.

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Year 2

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1 Acids, bases and salts

Learning objectives

After studying this unit, you should be able to:

1 define acids, bases and salts and state their properties
2 identify common chemical substances as acids, bases or salts and classify them according to their sources
3 prepare salts
4 describe the effects of acid–base indicators
5 use universal indicators and the pH scale to determine the pH of given solutions.

Background information

Production of chemicals by humans may be as old as human life itself. It stems from our natural curiosity about the environment and how we might use it to produce materials and objects that support life and improve the quality of human life.

Chemicals may be elements, or compounds formed during chemical processes. They make up the world around us and may be man-made or natural; elements, compounds or mixtures, for example, water, soil, air, fuel, soap and toothpaste.

The production of chemicals for specific purposes is a scientific and technological task. Many years of advances in their production have increased their number and variety. The variety is very wide and ranges from simple natural chemicals, such as water and common salt, to sophisticated synthetic materials such as plastics, textiles, medicines, foods, fertilisers and pesticides. It is important to appreciate their number and diversity, the way they improve our quality of life, and, equally important, the adverse effects they can have on the body and the environment. Chemicals are both a friend and a foe of the human race and the environment. An important group of chemicals are acids, bases and salts.

Sources of acids, bases and salts

Many acids, bases and salts occur in nature. They are widely used to sustain life and to live more comfortably. Figure 2.1 shows the wide range of chemicals associated with common salt, NaCl.

Acids, bases and salts can be prepared artificially (or 'synthesised') in the laboratory and on a large scale in industry. They also serve as starting or intermediate chemicals for the manufacture of many common and essential items.

Acids

Acids occur widely in nature. They may be formed through both natural and artificial processes. Vinegar, for example, contains ethanoic acid (acetic acid) and is used in the home for seasoning food. It is produced when carbohydrates, like sugar and glucose, ferment by the action of bacteria and air, first producing ethanol and then ethanoic acid. Vinegar has a sharp, sour taste. Bee stings are painful due to the injection of methanoic acid (formic acid) into the body by the bee. In the human body, when the body is tired and short of oxygen, the muscles release an acid (lactic acid) into the tissues, causing pain and cramps. Lactic acid is also produced when milk gets sour.

Acids originating from plants and animals, that is from organisms, are given the name **organic acids**, despite the fact that they can now be made synthetically. Methanoic acid, citric acid and tartaric

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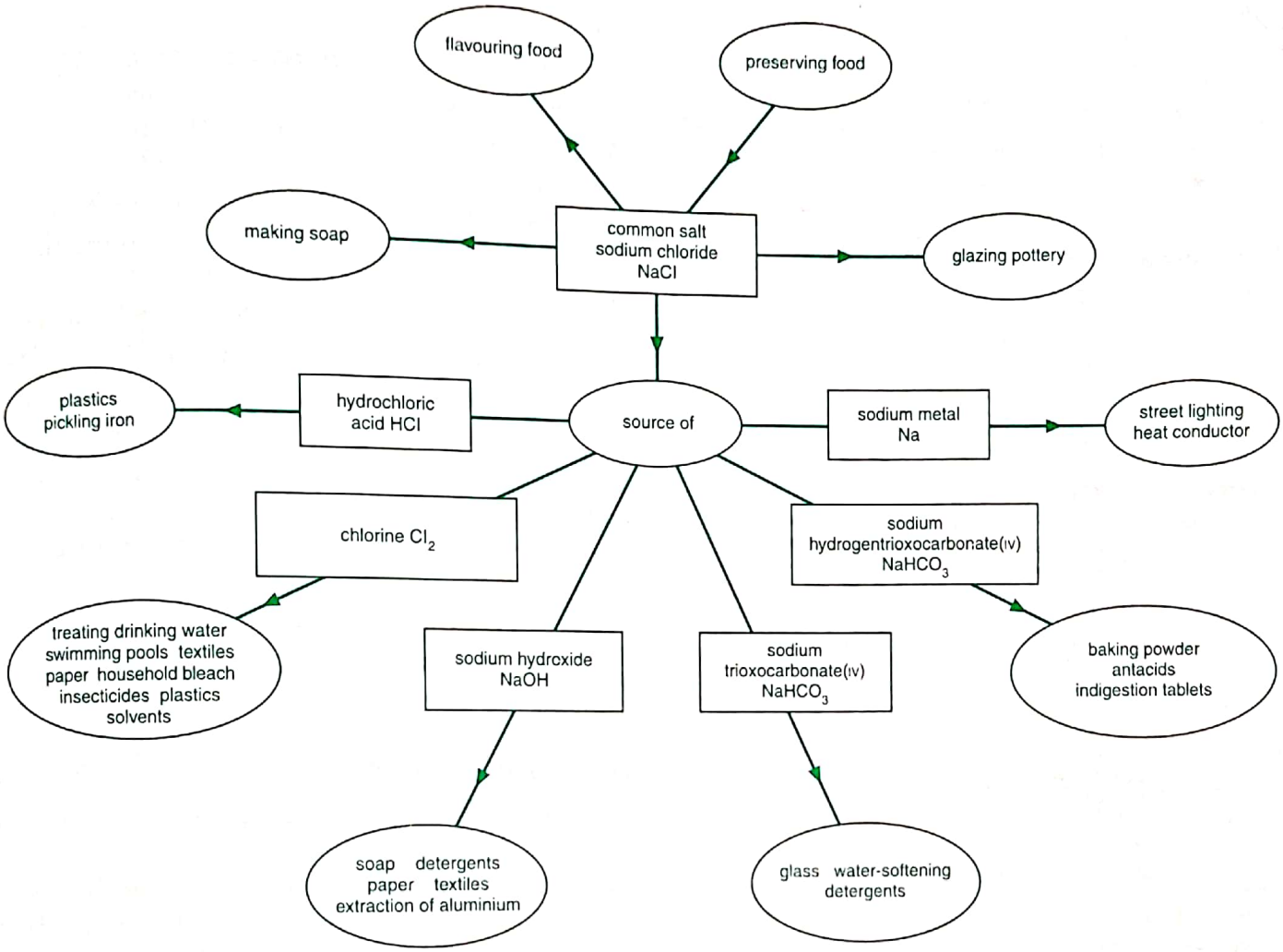


Fig 2.1 The uses of common salt and its products.

acid are examples of organic acids. Citrus fruits, such as oranges, lemons and grapefruits, contain citric acid. Citrus fruits, tomatoes, pawpaw, pineapple and green vegetables contain ascorbic acid, vitamin C. Fats and oils, such as palm oil and groundnut oil, are sources of fatty acids, such as stearic acid and palmitic acid. These contain long chains of carbon atoms, are usually solid and may not taste sour, unlike the other simpler acids. Amino acids are the small building units of proteins, essential for body growth and repairs.

Inorganic acids originate from mineral sources. Examples are hydrochloric acid, tetraoxosulphate(VI) acid and trioxonitrate(V) acid. Dilute acids can be found in the school laboratory. Dilute hydrochloric acid occurs in small quantities in the stomach of mammals and helps in the breakdown and digestion of food.

Sources of some acids in everyday life are shown in Figure 2.2.

Bases

Bases are obtained from nature when some plants are burnt to ash and the ash dissolved in water. For example, wood, plantain peels and cocoa husk ashes, dissolved in water, contain some potassium hydroxide. An **alkali** is a soluble base. Examples of alkalis are potassium hydroxide, sodium hydroxide and calcium hydroxide. Sodium hydroxide is produced industrially from common salt. Ammonia solution is ammonia gas dissolved in water. It interacts with water to give a low concentration of ammonium and hydroxide ions. Ammonia solution is a weak base, is alkaline, and behaves like a dilute solution of ammonium hydroxide.

Oxides of metals are bases; they occur in the Earth and most are insoluble in water. Some are the main ores from which metals are extracted for example, aluminium oxide, Al_2O_3 and iron(III) oxide, Fe_2O_3.

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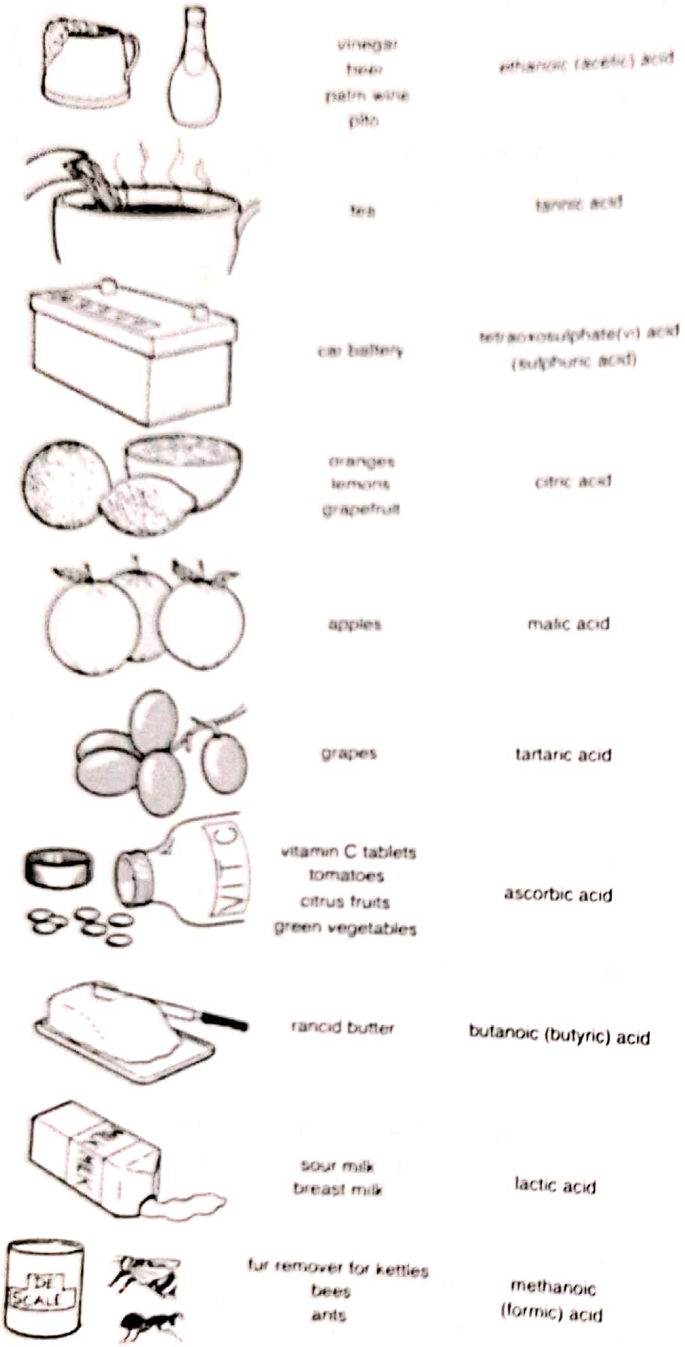


Fig 2.2 Sources of acids in everyday life.

Other important oxides are calcium oxide, CaO (lime) and magnesium oxide (magnesia), MgO. Calcium oxide is slightly soluble, giving limewater, aqueous $Ca(OH)_2$ and magnesium oxide is also slightly soluble, giving milk of magnesia, $Mg(OH)_2$.

Salts

Salts also occur widely in nature; there is a very large number of different salts. The most common is sodium chloride (common salt), NaCl, which is plentiful in sea water. The amount of sodium chloride in sea water at different places varies from 2.7–9.0 per cent. It also occurs as deposits of rock salt in some countries such as India, Germany, Nigeria and Poland.

Sodium trioxonitrate(V), $NaNO_3$ (Chile saltpetre) is another salt which occurs as a mineral in the Earth. As its common name suggests it is found in Chile, where, in very dry parts of that country it is found on the surface of the ground. Why do you think it is found where there is little or no rain?

Other natural sources of salts are oyster, crab and snail shells which contain calcium trioxocarbonate (IV), $CaCO_3$ and gypsum, calcium teraoxosulphate(VI) $CaSO_4$.

Bronsted–Lowry definition of acids and bases – proton transfer

Acids, bases and salts exist as molecules or ions. They interact with water and dissociate to produce protons. The proton is a positive hydrogen ion, H^+. In aqueous solution, it combines with the water molecule (hydrates) to form the hydroxonium ion, H_3O^+. This ion is also hydrated and often shown as $H_3O^+(aq)$ or simply as $H^+(aq)$. The protons in aqueous solutions of acids are responsible for many of their physical and chemical properties, for example, the sour taste, their effect on litmus and their reactions with metals and trioxocarbonates(IV). Strong acids dissociate fully to give a high concentration of $H^+(aq)$ ions, whilst weak acids dissociate partially to give a low concentration of $H^+(aq)$. The equations for the interaction of the strong acid, hydrochloric acid, and the weak acid, ethanoic acid, with water are:

$$HCl_{(g)} \xrightarrow{\text{water}} H^+(aq) + Cl^-(aq)$$

$$CH_3COOH(l) \xrightarrow{\text{water}} H^+(aq) + CH_3COO^-(aq)$$

Bases also dissolve in water to give hydroxide (OH^-) ions in their solutions. The equations for the base sodium hydroxide and ammonia are:

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$$NaOH(s) \xrightarrow{water} Na^+(aq) + OH^-(aq)$$
$$NH_3(g) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$$

Strong bases, such as NaOH and KOH, dissociate fully in water to give a high concentration of OH^- (aq) ions, whilst weak bases, such as aq NH_3 dissociate partially to give a low concentration of OH^- ions.

When an acid reacts with a base a proton is transferred from the acid to the base. In the example of sodium hydroxide and hydrochloric acid the equation is:

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

H^+(aq) is donated by HCl(aq) to be accepted by OH^- (aq) from NaOH(aq) to form water. The aqueous solution of the salt NaCl is formed in the process. At all times, when an acid reacts with a base in aqueous solutions a proton is transferred. This property of acids and bases was first put forward by Bronsted–Lowry and is used to define them.

By the Bronsted–Lowry definition:
An acid is a **proton donor**. A base is a **proton acceptor.**

This definition is useful in identifying acids and bases in aqueous and non-aqueous situations. See how aqueous solutions of some salts can be acidic, alkaline or neutral on page 198.

Properties and reactions of acids, bases and salts

Activity 1 To investigate some reactions of acids and bases

Caution: If acid or alkali splashes in the eye, the eye should immediately be washed with clean water. A slow stream of cool water is the best treatment for acids or bases in the eye, followed by professional medical advice and attention.

Part A: Acids

1 Put the following substances in separate test tubes:

Tube A – a 4 cm strip of magnesium ribbon
Tube B – a spatula full of sodium hydrogentrioxocarbonate(IV)
Tube C – 5 cm^3 of 1M sodium hydroxide plus a drop of litmus solution (see page 197)
Tube D – copper metal.
Tube E - small piece of oyster shell or marble chips or a spatula full of sodium trioxocarbonate(IV).

2 Add aqueous hydrochloric acid (about 1M) to each test tube until any reaction ceases. Check the temperature of the mixture before and after the acid is added either by putting your hand round the tube or by using a thermometer.

3 Test the gas evolved from Tube A with a burning splint and that evolved from Tube B and Tube E with limewater using a gas delivery tube (see Figure 2.3).

4 Describe all the tests and record all your observations and gas evolved in a table like the one below. The first test is described for you. The observations should include colour, smell, change in temperature and effect on litmus paper.

Tests	Observations	Gas evolved, if any
tube A A small strip of Mg metal was put into a test tube. Dil HCl was added		

Part B: Reaction of a base with an ammonium salt and test for ammonia gas

5 Put a spatula full of calcium oxide, CaO, powder into a test tube, followed by a few crystals of ammonium chloride, NH_4Cl. Warm the mixture gently and cautiously smell the gas.

Caution: Use your hand to wave some of the gas to your nose – don't smell from the tube directly.

Test the gas with moist red litmus paper.

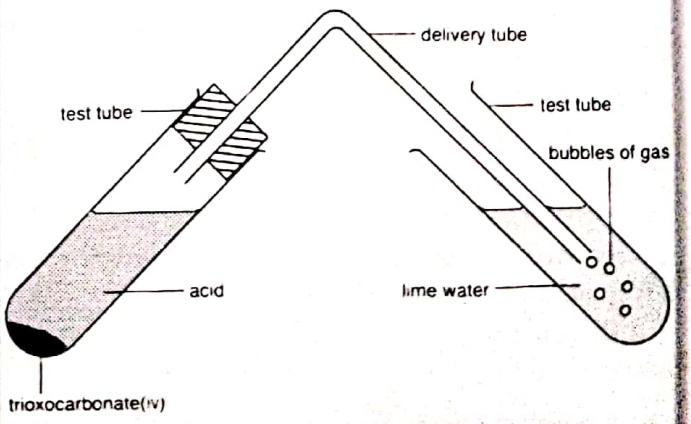


Fig 2.3 Testing a gas with limewater.

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Fig 2.4 Smelling a gas.

6 Record your observations; what deductions can you make from these tests?

7 As a further test, shake a bottle of concentrated hydrochloric acid gently. Remove the stopper and bring it near the mouth of the test tube in which the gas is being given off. The formation of white fumes identifies the gas as ammonia. This is a test for ammonia gas.

Part C

8 Write equations, in words and formulae, for all the reactions which have taken place in Parts A and B. The formulae of some of the substances are: magnesium, Mg; sodium trioxocarbonate(iv), Na_2CO_3; sodium hydrogentrioxocarbonate(IV), $NaHCO_3$; oyster shell, calcium trioxocarbonate(IV); sodium hydroxide, NaOH.

9 In which of the reactions was heat given out?

Reaction of acids with metals and test for hydrogen gas

Dilute aqueous solutions of acids react with many metals, such as magnesium, zinc and iron, to give off hydrogen gas. The metal displaces the hydrogen in the acid, to form a salt and hydrogen gas. Hydrogen may be recognised because it burns with a squeak or pop sound when a lighted splint is placed in it. This is the test for hydrogen gas. The sound is the result of a small explosion caused when hydrogen gas reacts with oxygen in the air.

Caution: Dangerous explosions take place when larger amounts of hydrogen are used.

The reaction in Tube A in Activity 2, can be summarised by the equation (in words and formulae):

magnesium + hydrochloric acid → magnesium chloride + hydrogen gas

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

The magnesium metal has replaced the hydrogen atom of the hydrochloric acid. The salt produced in this reaction is called magnesium chloride, $MgCl_2$.

Some metals, such as copper, do not react with many dilute acids. This is because copper is below hydrogen in the reactivity series (see Table 3.5 on page 353).

Trioxonitrate(V) acid is an exception. This reacts vigorously with many metals but does not usually produce hydrogen; other products are formed such as oxides of nitrogen and a salt, for example, copper(II) trioxonitrate(V) if copper is used (Tube D in Activity 2).

In summary:

- metals above hydrogen in the reactivity series (Table 3.5) react with tetraoxosulphate(VI) acid and hydrochloric acid to release hydrogen gas
- metals below hydrogen in the reactivity series do not react with these acids under similar conditions
- trioxonitrate(V) acid rarely gives off hydrogen with metals, but produces oxides of nitrogen; it attacks copper, but not gold or silver, which are below copper in the reactivity series.

The reactivity series can be thought of as an arrangement of metals according to their ability to replace the hydrogen atom in acids. Metals which replace the hydrogen atom easily are at the top of the series; the reactivity of the metals decreases as we go down the series.

Reaction of acids with trioxocarbonates(IV) and test for CO_2 gas

Trioxocarbonates(IV) and hydrogentrioxocarbonates(IV) fizz vigorously (or effervesce) with carbon dioxide gas. When the carbon dioxide gas is bubbled through limewater, it turns milky (see Figure 2.3). This is the test for carbon dioxide gas. The reaction can be used to prepare carbon dioxide gas. The milky suspension is calcium trioxocarbonate(IV) particles which are insoluble in water. The equations for the reactions in Tubes B and E of Activity 1 are:

Sodium hydrogen-trioxocarbonate(IV) + hydrochloric acid → sodium chloride + carbon dioxide + water

$NaHCO_3(s) + 2HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O$

Sodium trioxocarbonate(IV) + hydrochloric acid → sodium chloride + carbon dioxide + water

$Na_2CO_3(s) + 2HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O$

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The equation for formation of the milky suspension of calcium trioxocarbonate(IV), $CaCO_3$, in water is:

Calcium hydroxide (limewater)	+	carbon dioxide	→	calcium trioxo-carbonate(IV)	+	water
$Ca(OH)_2(aq)$	+	$CO_2(g)$	→	$CaCO_3(s)$	+	$H_2O(l)$

The further reaction of excess carbon dioxide with the milky suspension ($CaCO_3$) gives a clear solution, because of the formation of the soluble salt, calcium hydrgencarbonate(IV), $Ca(HCO_3)_2(aq)$.

$$\underset{\text{milky suspension}}{CaCO_3(s)} + CO_2(g) + H_2O(l) \rightarrow \underset{\text{water soluble}}{Ca(HCO_3)_2(aq)}.$$

Carbon dioxide gas dissolves slightly in water, to give an acid solution, which turns litmus red. It extinguishes a lighted splint, as it does not support combustion. On page 322 we will discuss its uses to extinguish fires.

The reaction of sodium hydrogentrioxocarbonate (IV) with acid, is used to relieve indigestion caused by excess acid in the stomach. Health or fruit salts called **antacids** contain organic acids, for example, citric and tartaric acids, and sodium hydrogentrioxocarbonate(IV). When water is added, there is vigorous fizzing, leaving an excess of the sodium hydrogentrioxocarbonate(IV) in the mixture (see Figure 2.5). When the mixture is drunk, it reacts with excess acid in the stomach and often relieves the cause of indigestion. The sharp taste of the gassy mixture refreshes the person.

In the school laboratory or the home kitchen, spills of acidic substances can be treated with dilute aqueous sodium trioxocarbonate(IV) to remove the acid, for example from the floor. The neutral mix can be wiped up and the floor thoroughly washed with water.

Kettle fur, or scale, found inside containers in which hard water is often boiled, is the white solid of calcium trioxocarbonate(IV), $CaCO_3$. The fur or scale can be removed by washing or rinsing with weak methanoic acid or ethanoic acid. Wash out the kettle with water before using it again.

Reactions of bases with ammonium salts and test for NH_3 gas

Bases in the solid state or in aqueous solution produce the pungent smelling gas, ammonia, NH_3, when they are warmed with an ammonium salt. Ammonia gas turns red litmus blue. It is the only common alkaline gas. The equation for the reaction in Part B of Activity 1, is:

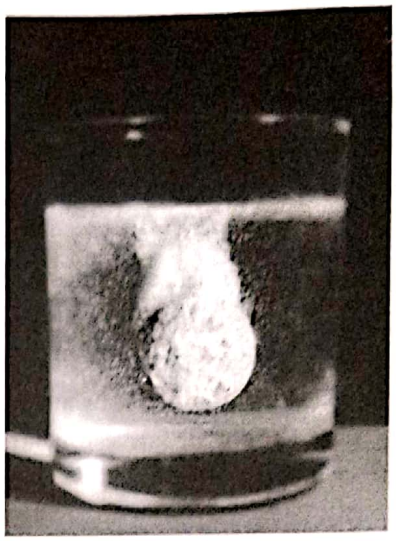


Fig 2.5 Antacid fizzing in water.

Ammonium chloride	+	calcium hydroxide	warm →	calcium chloride	+	water	+	ammonia
$2NH_4Cl(s)$	+	$Ca(OH)_2(s)$	→	$CaCl_2(s)$	+	$2H_2O(l)$	+	$2NH_3(g)$

Ammonia gas gives white fumes of ammonium chloride when brought into contact with hydrogen chloride gas in the test for ammonia gas. Hydrogen chloride gas comes from the concentrated hydrochloric acid. The equation is:

Ammonia	+	hydrogen chloride	→	ammonium chloride
$NH_3(g)$	+	$HCl(g)$	→	$NH_4Cl(s)$

Neutralisation reactions of acids and bases

Neutralisation is the reaction between an acid and a base to produce a salt and water. It is called neutralisation because, in the reaction, both the acid and the base properties are lost, or neutralised.

Neutralisation of strong acids and bases is usually accompanied by heat being given off. The equation for the reaction in Tube C in Activity 1 is:

Hydrochloric acid	+	sodium hydroxide	→	sodium chloride	+	water	+	heat
HCl	+	NaOH(aq)	→	NaCl	+	$H_2O(l)$	+	heat

The equation for the reaction of dilute trioxonitrate(V) acid and calcium oxide is:

Trioxonitrate(V) acid	+	calcium oxide	→	calcium trioxonitrate(V)	+	water	+	heat
$2HNO_3(aq)$	+	$CaO(s)$	→	$Ca(NO_3)_2(aq)$	+	$H_2O(l)$	+	heat

Tarnished or rusty metal surfaces can be treated with an acid mixed with an abrasive. The tarnished or rusty

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surface coating is often an oxide. This oxide reacts with the acid in a neutralisation reaction and the abrasive helps in scraping it off the metal surface by friction, thus restoring the original lustrous surface of the metal. In industry this is called **pickling**.

Salts

> A **salt** is formed by the replacement of the hydrogen atom in an acid by a metal or by the ammonium ion. A salt is made up of a metal or ammonium ion, which is positive, and a negative ion. The negative ion or anion comes from the acid.

Table 2.1 shows examples of salts and the acids and bases from which they can be obtained.

Table 2.1 Salts and acids and bases from which they can be obtained

Salt	Acid	Base/other possible reactant
sodium chloride, (NaCl)	HCl	NaOH or Na_2O or Na_2CO_3
copper(II) tetraoxo-sulphate(VI) $CuSO_4$	H_2SO_4	$Cu(OH)_2$, CuO or $CuCO_3$
zinc chloride, $ZnCl_2$	HCl	ZnO, $Zn(OH)_2$ or $ZnCO_3$
ammonium chloride, NH_4Cl	HCl	$NH_3(aq)$ or $NH_3(g)$

Uses of acids, bases and salts

Acids, bases and salts are widely used in the school, home, industry and other places. A look at Figures 2.6, 2.7 and 2.8 shows how human beings depend on these substances and other things made from them. Ghana has not yet developed a chemical industry to make all these substances. However, industry in Ghana is developing and today manufactures some of the products directly from raw materials from Ghana and other countries.

For example, soap and detergents, laundry and toilet soaps such as 'Guardian' bar soap, 'Omo' and 'Breeze' are manufactured by Lever Brothers, Ghana Limited, Tema (see Figure 2.9). Other examples are:

- Fizzy drinks, for example, mineral drinks such as 'Coca Cola', are produced in Ghana. These contain trioxocarbonate(IV) acid, that is, carbon dioxide dissolved in water under pressure.
- Common salt is manufactured in Ghana in large quantities for home use and export. The raw materials are sea water and sunlight.
- Whitewash paint, which is mainly made of the base limewater (calcium hydroxide), is a by-product of a factory at Tema, which produces acetylene gas for heating (*L'Air Liquide* Ghana Limited). It is also produced by strongly heating calcium trioxocarbonate(IV) (limestone), $CaCO_3$, in oyster shells to form calcium oxide, CaO. The CaO is then dissolved in water to form calcium hydroxide, $Ca(OH)_2$. Oyster shells are in great abundance in many towns down the Volta River in Ghana.

The important acid, tetraoxosulphate(VI) acid and base, sodium hydroxide (caustic soda) are not manufactured in Ghana but are imported. They form the base for the manufacture of many essential items (see Figures 2.7 and 2.8).

ACTIVITY 2 Activities in a salt or chemical industry

1 Visit a salt or chemical industry if possible or use the internet or textbooks to investigate the activities in these industries.

2 *Work in groups* to discuss your findings and write a group report

Preparation of salts

In 'Sources of acids, bases and salts' we defined a salt as the substance formed when the hydrogen atom of an acid is replaced with a metal or ammonium ion in a reaction. Examples of salts are sodium chloride, NaCl, copper(II) tetraoxosulphate(VI), $CuSO_4$ and zinc trioxonitrate(V), $Zn(NO_3)_2$. Several of the reactions studied so far produce salts.

The method used to prepare a salt depends on whether the salt is insoluble or soluble in water (see Figure 2.10).

Precipitation method

Insoluble salts are prepared by the **precipitation method**. Solutions of the two soluble salts, containing the ions of

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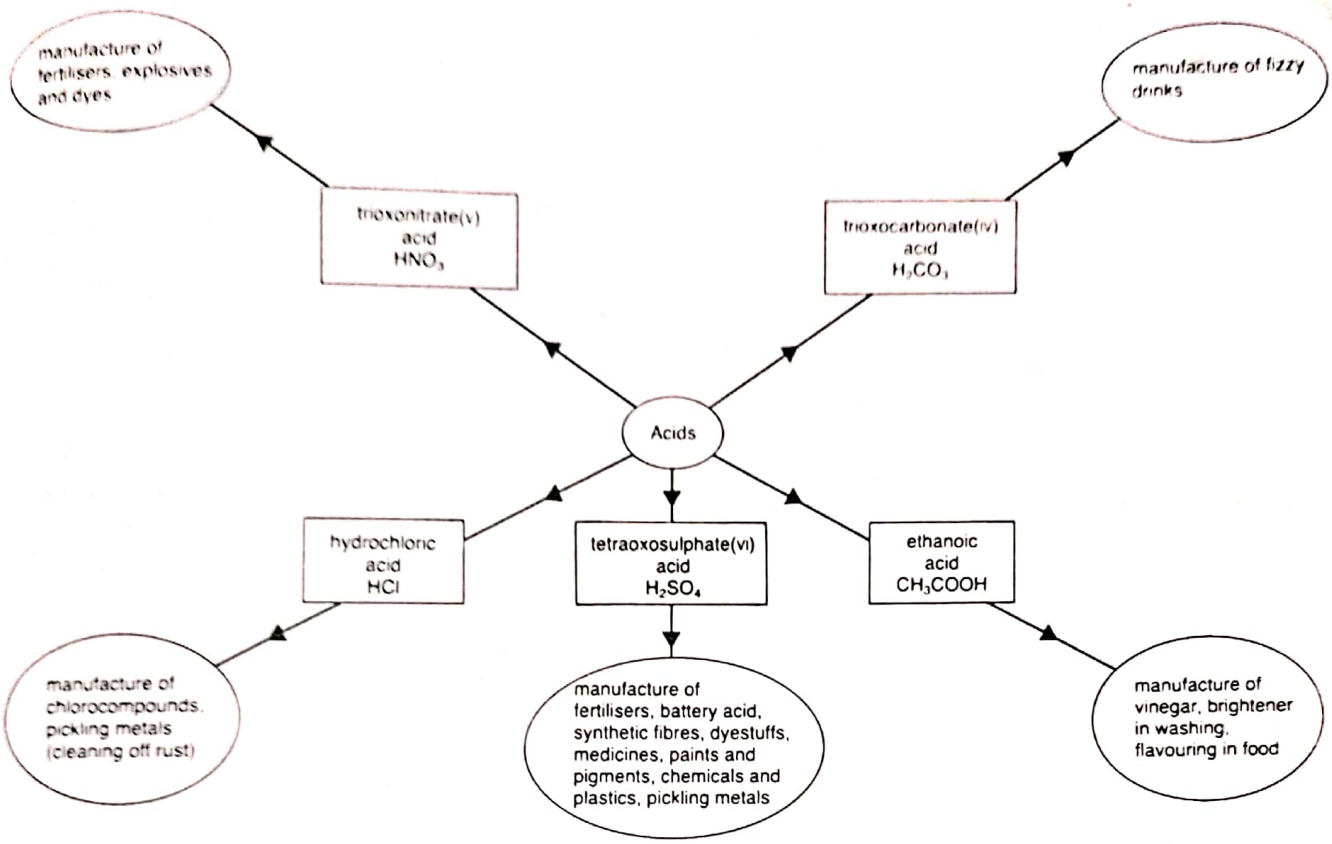


Fig 2.6 Uses of some acids.

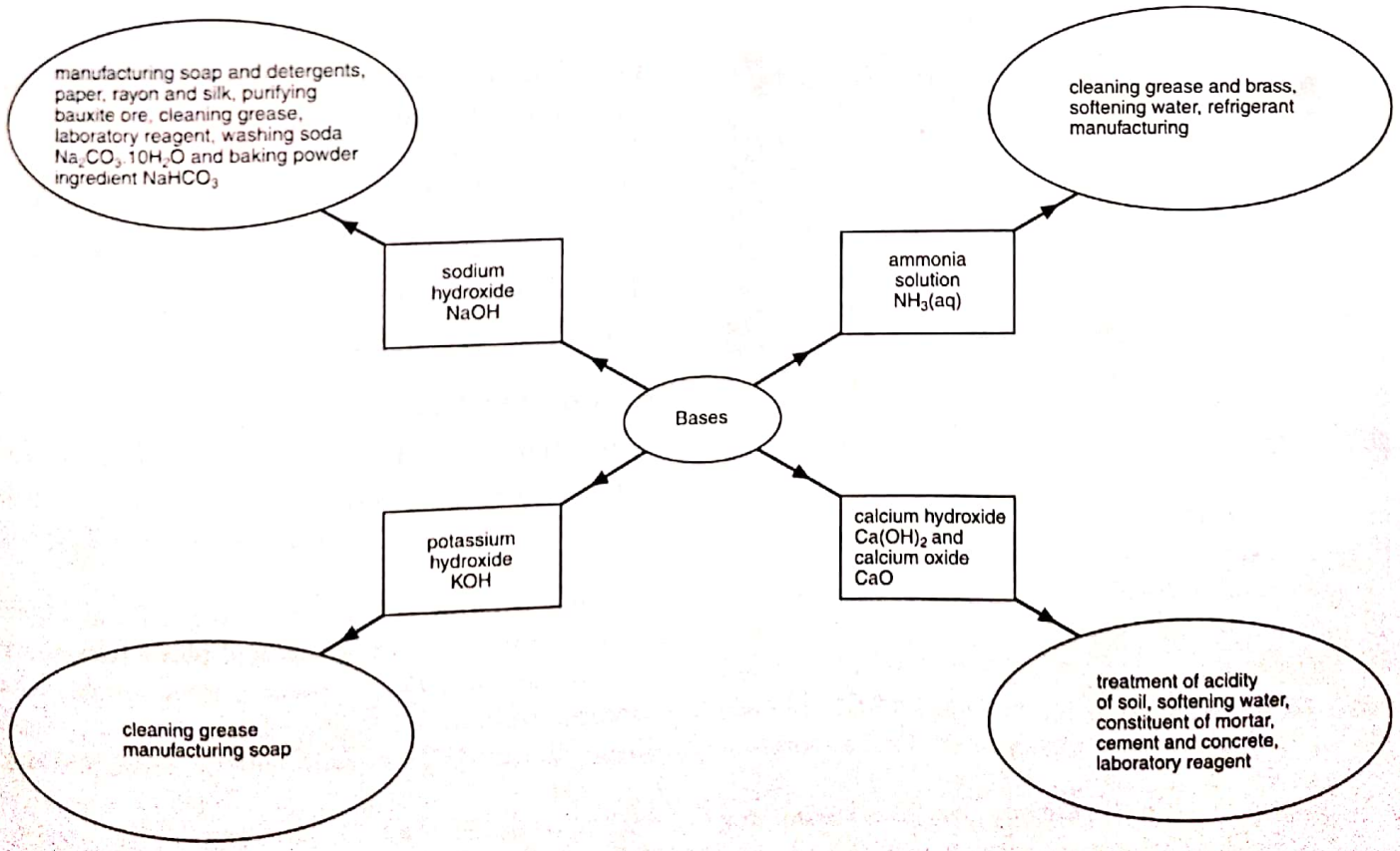


Fig 2.7 Uses of some bases.

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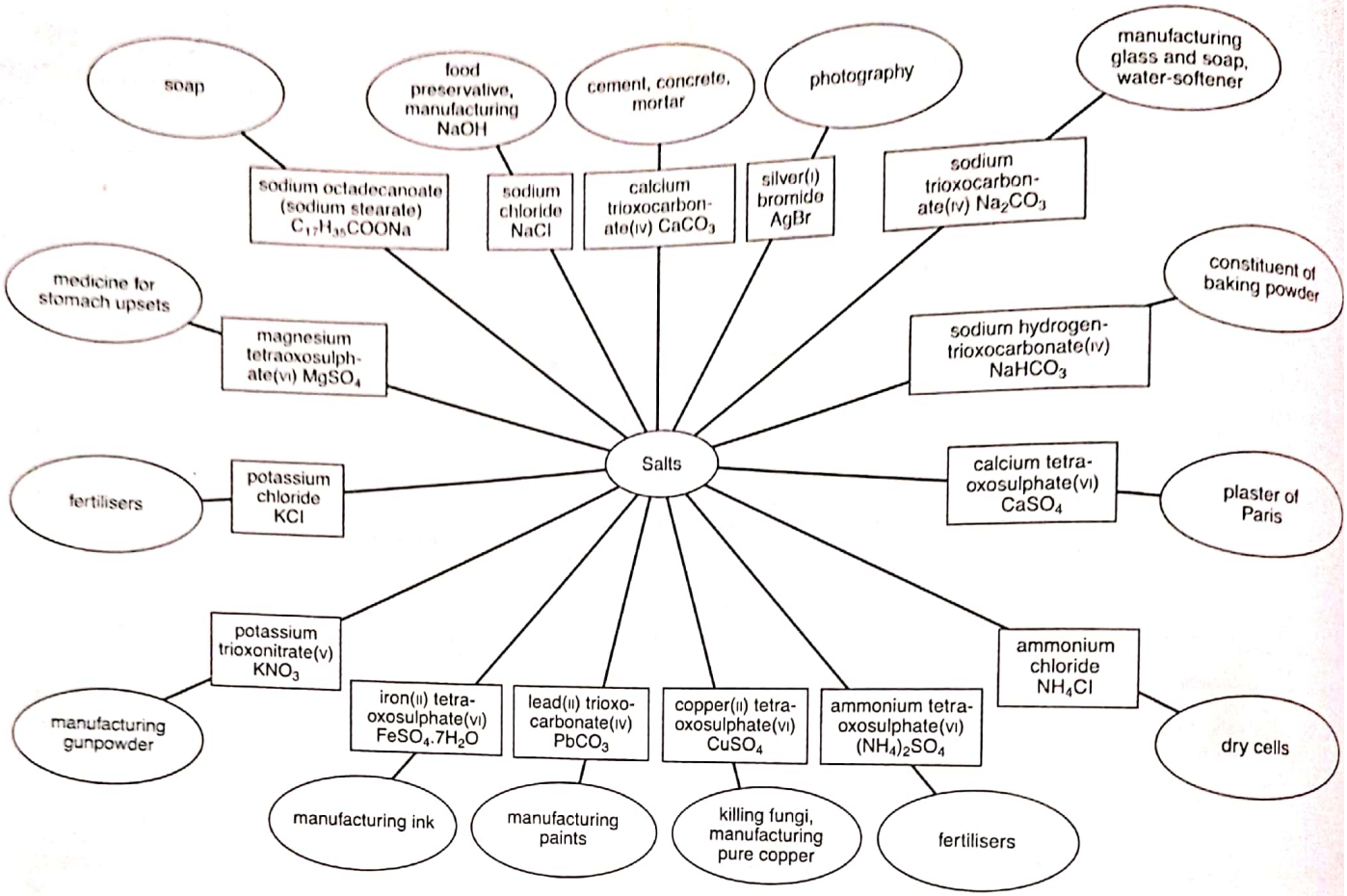


Fig 2.8 Uses of some salts.



Fig 2.9 Locally produced soap

the insoluble salts, are mixed and a precipitate is formed. The precipitate is filtered, washed with distilled water and dried. Examples of insoluble salts are lead(II) chloride, $PbCl_2$, lead(II) tetraoxosulphate(VI), $PbSO_4$, calcium tetraoxosulphate(VI), $CaSO_4$ and silver(I) chloride, AgCl.

For example, lead(II) chloride is prepared by mixing solutions of lead(II) trioxonitrate(V), $Pb(NO_3)_2$ and sodium chloride, NaCl, both of which are soluble salts. Between them they contain the required lead(ii), Pb^{2+} and chloride, Cl^- ions.

The equation for the preparation of lead(II) chloride is:

$$Pb(NO_3)_2(aq) + 2NaCl(aq) \rightarrow PbCl_2(s) + 2NaNO_3(aq)$$

The ionic equation is:

$$Pb^{2+}(aq) + 2Cl^- \rightarrow PbCl_2(s)$$

Titration method

The **titration method** is used to prepare a soluble salt using two reactants which are water-soluble, so their solutions can be easily prepared (see Figures 2.10 and 2.11).

Sodium chloride is soluble in water. From Figure 2.11 we see that we can use an acid plus a base, metal or trioxocarbonate(IV) to prepare it. A suitable base is soluble sodium hydroxide. We could use sodium trioxocarbonate(IV) instead but not sodium metal. Why not?

We have chosen a soluble base, which will enable its solution to be prepared, so that the titration method

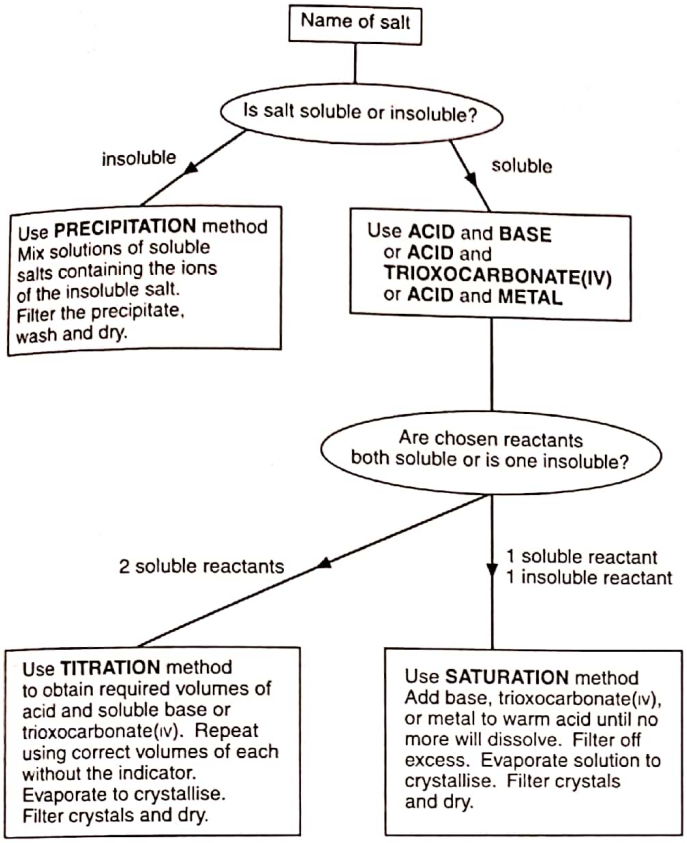


Fig 2.10 Flowchart to identify suitable methods for the preparation of salts based on their solubility in water.

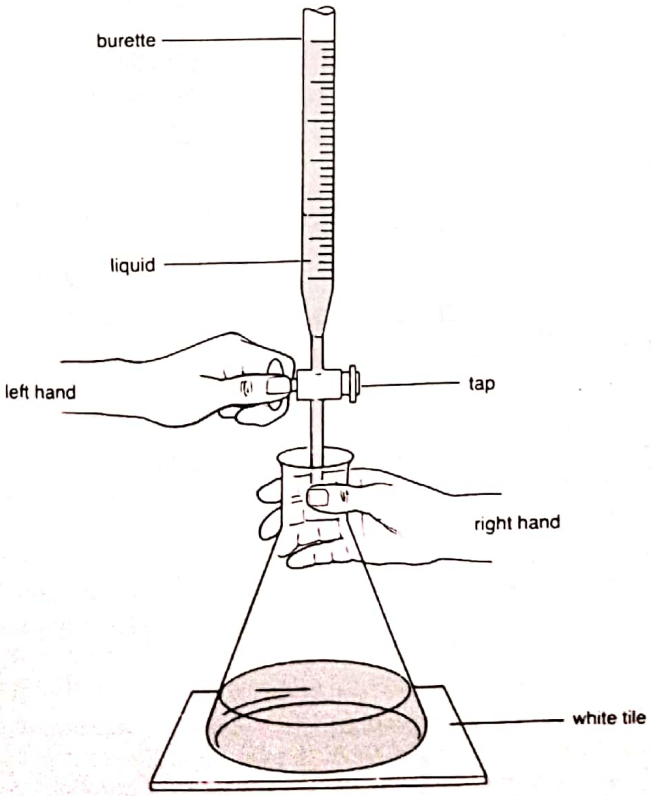


Fig 2.11 Preparation of a salt by the titration method.

can be used. This involves neutralising the alkali with the acid, followed by evaporation of the mixture to obtain the salt.

Titration is a method in which a solution of known concentration is added in small volumes to a fixed volume of another solution until the point of neutralisation, or end point, is reached. The end point is determined by using a suitable indicator.

Activity 3 To prepare the salt sodium chloride by the method of titration

Part A

1 Pipette exactly 25 cm^3 of 2M sodium hydroxide solution into a conical flask.

2 Fill the burette with 2M hydrochloric acid. Release a little acid into a beaker to drive out any air bubbles. Take the initial reading on the burette (to one decimal place) and record it in a table like the one on page 197. Make sure the volume is read correctly, that is, with the horizontal eye level with the bottom of the meniscus.

3 Add one or two drops of phenolphthalein indicator to the sodium hydroxide in the flask. Record its colour.

4 Adjust the burette over the flask (see Figure 2.11) and release the acid in small volumes into the flask (about 0.5 cm^3 to start with). Swirl the flask contents around until any new colour developed appears not to fade away easily. From then on, add the acid drop by drop until one drop brings about a permanent colour change. Take the final reading on the burette (to one decimal place) and record it.

Volume of acid/ cm^3	First titration	Second titration
final reading		
initial reading		
difference		
average		

5 Repeat steps 1–4 but this time release acid (an amount just below the volume obtained in the first titration) in one go, then add the acid drop by drop until one drop gives a clear end point.

Record the volume required. Find the average of the two volumes of the acid.

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Part B

6 Pipette 25 cm^3 of the sodium hydroxide solution into a flask but this time without the indicator. Use the burette to add the average volume of acid needed to neutralise it. Mix the solutions well and heat the mixture in an evaporating dish to evaporate it to near-dryness. When nearly dry, allow it to cool and crystallise.

Describe the colour of the crystals. Ask your teacher if you can taste your product; if allowed, record the taste.

7 Write an equation for the reaction, using chemical formulae. Write names beneath all the substances. Write the ionic equation. What is the meaning of the term 'end point'?

Activity 4 To review the methods of preparing salts

1 Select another type of reaction which can produce sodium chloride and write an equation for that change. You will need to select a different base this time.

2 Name two salts (other than lead(II) chloride and sodium chloride) that can be prepared by the:
(a) titration method
(b) precipitation method.

For 2(a), identify and name each base. For 2(b), identify the reagents that would be suitable in each case.

3 Describe, in outline giving equations, how you would prepare one named salt by the saturation method (Figure 2.11).

Acid–base indicators, the pH scale and universal indicator

Acid–base indicators

Plant and synthetic dyes, such as litmus, can change colour in acidic, alkaline and neutral solutions. The colour changes can be used to determine whether a solution is acidic, alkaline or neutral. These dyes are known as **acid–base indicators**.

Litmus has a purple colour when neutral. It changes to red in acidic solutions and blue in alkaline solutions. Neutral solutions, such as common salt solution, do not affect the colour of litmus solution or litmus paper – it remains purple. Table 2.2 shows the colours of different indicators in acids, alkalis and neutral solutions. Litmus is often available as red and blue paper. Red and blue litmus paper does not change colour in neutral solutions. Red litmus paper turns blue in a base and blue litmus changes to red in an acid.

Table 2.2 Colours of some indicators in acid, alkaline and neutral solutions

Indicator	Colour in acid solution	Colour in neutral solution	Colour in alkaline solution
litmus	red/pink	purple	blue
phenolphthalein	colourless	colourless	pink/red/rose
methyl orange	red/pink	orange	yellow

Activity 5 To study the effects of acids, alkalis and salts on litmus indicator

1 Pour about 3 cm^3 each of dilute hydrochloric acid, dilute sodium hydroxide solution, distilled water and sodium chloride solution into four test tubes.

2 Add a few drops of purple litmus solution (neutral) to each tube in turn. Shake the tube carefully and note any colour change. Record your observations in a table like the one below. Alternatively, drops of each solution can be put on litmus paper separately.

Solution	Colour after litmus added	Solution is acidic/alkaline/neutral?
dilute hydrochloric acid		
dilute sodium hydroxide		
distilled water		
sodium chloride solution		

3 Decide whether the solutions are acidic, alkaline or neutral (see Table 2.2) and record this in the last column of the table.

4 Repeat the tests using blue and red litmus paper.
(a) Put one or two drops of each solution on the paper, placed a clean surface for example, a palette or tile. Allow the colour to develop and record it a table as above.

Note: Do not put the litmus paper into the solutions in test tubes for the dyes to be washed into the solutions. This may give erroneous colour changes in respect of the colours of the solutions.

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Activity 6 To use the colour changes of litmus indicator to classify substances as acidic, alkaline or neutral

1 Repeat steps 1 and 2 of Activity 5 using: orange, lemon and tomato juices, sugar, soap, wood ash, plantain peel ash, common salt (sodium chloride), sodium trioxocarbonate(IV), ammonium chloride, limewater, soil suspensions, akpeteshie, soft mineral drinks, beer and toothpaste. Make a table to record your observations.

Note: You may have to use a suspension of wood and plantain peel ash for this test. Let the ash settle (or filter it) before trying to use the litmus.

2 In the last column of your table, classify each solution as acidic, alkaline or neutral, based on your observations.

3 (a) Which of the following solutions is more alkaline – limewater or sodium trioxocarbonate(IV); more acidic – ammonium chloride or tomato juice?
(b) Is it easy or possible to determine the degree of acidity alkalinity using litmus solution?

Acid–base indicators change colour in acidic, alkaline or neutral solutions. This property is used to classify a substance dissolved in water as an acid, a base or a neutral substance. Acid–base indicators can be extracted from natural plants or can be prepared artificially. Litmus is extracted from the micro-organic plant, lichen. Many coloured flowers contain dyes that change colour in acid, base or neutral solutions, for example, hibiscus.

Other acid-base indicators are methyl orange and phenolphthalein (Table 2.2). These are solid artificial dyes and are dissolved in solvents such as ethanol, for use in the laboratory.

You would have observed in Activity 6 that Na_2CO_3 solution turned litmus blue; NaCl solution did not change the colour of litmus and NH_4Cl turned litmus pink.

These observations can be explained when the ions in the salts are considered to react with water molecules in the aqueous solution. H_2O molecules react with anions of weak acids for example, CO_3^{2-} and CH_3COO^- to produce OH^- ions and make it alkaline. The OH^- ions produced makes it turn litmus blue. By the Bronsted-Lowry definition, the CO_3^{2-} anion acts as a proton acceptor and is therefore a base.

$$CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$$

Similarly, aqueous solutions of salts from weak bases and strong acids for example, NH_4Cl and $AlCl_3$ are acidic due to the reaction of the cations NH_4^+ and hydrated Al^{3+} with water molecules to produce H_3O^+ ions in a **Bronsted–Lowry acid–base reaction.**

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$

The NH_4^+ donates a proton and therefore acts as an acid; the H_3O^+ ($H_2O + H^+$) is equivalent to a proton and this turns litmus pink.

Salts from strong acids and strong bases for example, NaCl and K_2SO_4 are neutral because none of their component ions interact with water.

Activity 7 To find out the colour of methyl orange and phenolphthalein indicators in various solutions

Part A

1 Pour 3 cm^3 each of dilute hydrochloric acid, dilute sodium hydroxide solution, sodium chloride solution and distilled water into separate test tubes. Add one or two drops of methyl orange indicator to each test tube. Shake well and record the colour change for each test tube in a table like the one below.

2 Repeat step 1 with phenolphthalein indicator.

3 From your results in Activity 4 fill in whether the solutions in the second column of your table are acidic, alkaline or neutral.

4 Predict the colour of lemon juice in methyl orange and phenolphthalein indicators.

Carry out the tests to confirm your prediction.

Part B

5 Put about 5 cm^3 of dilute hydrochloric acid (0.1M) into a long test tube. Add two drops of methyl orange indicator to the dilute acid in the test tube, shake the tube and record the colour. Add dilute sodium hydroxide (0.1 M) drop by drop, shaking the tube between additions. Be patient and don't rush the activity. Record the colour changes until there is no further colour change. You will then have added excess sodium hydroxide solution.

6 Repeat step 5 with phenolphthalein indicator.

Solution	Acidic, alkaline or neutral	Colour change of methyl orange	Colour change of phenolphthalein
dilute hydrochloric acid			
dilute sodium hydroxide			
distilled water			
sodium chloride solution			

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7 Think about your observations and answer these questions for both methyl orange and phenolphthalein.
(a) What is the colour of each indicator in an acidic solution and an alkaline solution?
(b) Do you know when the solution was neutral? Describe the colour change(s) at that point.
(c) If phenolphthalein is added to a small volume of an alkaline solution, what colour would you observe? If you now add acid of equal concentration drop by drop until the volume is more than that of the alkaline solution, what colour changes would you observe? Explain the causes of the colour change(s).

8 Predict the colour of aqueous solutions of Na_2CO_3 and NH_4Cl in
(a) methyl orange
(b) phenolphthalein.

The pH scale

All aqueous solutions of substances contain some hydrogen and hydroxyl ions. The acidity or alkalinity of the solution are related and depend on the balance of the concentration of these two ions. For example, the two ions determine the sourness or bitterness of aqueous solutions and how the solutions interact with other substances. The measurement of the concentration of the hydrogen ion is used to measure the balance of the two ions in aqueous solutions.

pH is a measure of the hydrogen ion concentration of a solution. pH measures the degree of acidity and alkalinity of dilute solutions with simple numbers.

For example, a solution of hydrogen ions of concentration 0.001M has pH3 but it is more convenient to use pH 3 than 0.001M. Note that solutions with high concentrations of hydrogen ions (above 2M) have negative pH values outside the convenient simple number range of 0–14 allowed on a pH scale. pH is therefore not used on solutions with very high concentrations of hydrogen ions.

- The pH scale runs from 0–14, with pH 7 as the neutral point.
- Solutions of pH below seven are acidic; the acidity increases from pH numbers seven to zero; pH 0 is strongly acidic.
- Solutions with pH above seven are alkaline; alkalinity increases from seven to fourteen, pH 14 is very alkaline.

Universal indicator

It is sometimes difficult to judge the colours of indicators in solution exactly and a difference of plus or minus one pH unit can occur. Indicators such as litmus can only show whether a solution is acidic or alkaline.

A **universal indicator** is a mixture of acid base indicators which shows a series of colour changes at different pH (see Figure 2.12).

- A single indicator such as litmus, methyl orange or phenolphthalein shows only whether the solution is acidic or alkaline. It has only two colour indications. It changes colour over a narrow pH range.
- Universal indicator changes to several colours at different pH values and can show how acidic or alkaline the solution is. It is red or pink in acid solution, blue to violet in alkaline solution and green in a neutral solution.
- Universal indicator can be used to estimate the pH of a solution.

A universal indicator is available in solution or paper form accompanied by a standard colour chart and matching pH values. This enables you to determine whether the solution is acidic or basic and also the degree of acidity or alkalinity (figure 2.12).

Activity 8 To estimate out the pH of some acids and alkalis using universal indicator

1 Add one or two drops of distilled water and sodium chloride solutions to separate strips of universal indicator paper. Allow the colour to develop and match it with the colour chart. Determine the pH and record it in a table like the one below.

Solution	Colour of Universal indicator	pH
distilled water		
sodium chloride		
hydrochloric acid, 0.01 M		
ethanoic acid, 0.01 M		
hydrochloric acid, 0.001 M		
ethanoic acid, 0.001 M		
sodium hydroxide, 0.01 M		
ammonia solution, 0.01 M		

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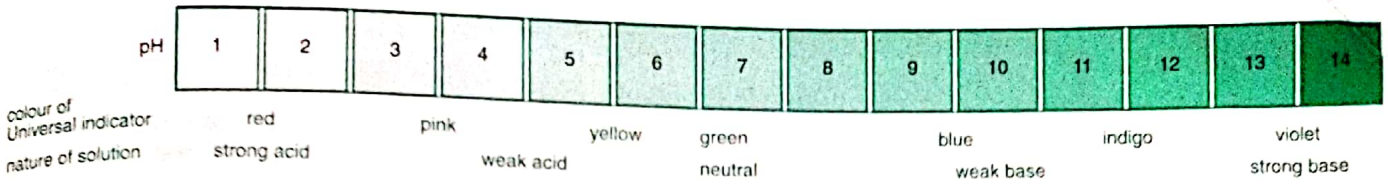


Fig 2.12

2 a) Using the same concentration (0.01 M) of hydrochloric and ethanoic acids, add one or two drops of each to a (separate) strip of universal indicator paper. Determine the pH and record it in the table.

b) Repeat step 2a with 0.001M solutions.

Which gave the lower pH value? Which was the strongest acid?

3 Repeat step 2a using 0.01M sodium hydroxide and 0.01M ammonia solutions.

Which gave the highest pH value? Which was the stronger alkali? Explain.

4 Draw a pH scale and mark on it the solutions you used, with their concentrations.

From Activity 8 you would notice that even when the acids or alkalis compared had the same concentrations, for example, sodium hydroxide and ammonia, they had different pH values. That is because pH measures the concentration of hydrogen in the solution while the strength measures the degree of dissociation of the acid or base. The strength of an acid or of an alkali (base) is different from its concentration. Sodium hydroxide dissolves to produce more OH^- ions (less H^+ ions) and therefore has a higher pH.

Many plant diseases are caused or made worse by extremes of pH, sometimes because this makes essential nutrients unavailable or because the soil itself is unhealthy.

The pH of soil can be measured using universal indicator paper. A small sample of soil is mixed with distilled water, into which a strip of indicator paper is inserted. The colour change of the indicator paper is noted and compared with the colours on the pH scale to obtain a pH reading.

A **weak acid or alkali** is only slightly dissociated in solution to give few hydrogen or hydroxide ions respectively (lower concentration). A **strong acid or alkali** dissociates completely in solution to give a large number of hydrogen or hydroxide ions respectively (higher concentration).

Table 2.3 Strengths of acids and alkalis

Group	Strong	Weak
acids	hydrochloric acid	ethanoic acid
	tetraoxosulphate(vi) acid	trioxocarbonate(iv) acid
	trioxonitrate(v) acid	lactic acid
		citric acid
alkalis	sodium hydroxide	ammonia solution
	potassium hydroxide	urea
	calcium hydroxide (limewater)	

Summary of the properties of acids and bases

Acids:

- taste sour
- change litmus paper to red
- have a pH less than 7
- are very corrosive when concentrated
- react with bases in neutralisation reactions to give salts
- react with trioxocarbonates(IV) to give effervescence of carbon dioxide gas
- react with reactive metals to give off hydrogen gas.

Bases:

- taste bitter
- change litmus paper to blue
- have a pH greater than seven
- have a slippery or soapy feel
- are very corrosive in solid or concentrated form
- react with acids in neutralisation reactions to give salts.
- react with ammonium salts to give ammonia gas.

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Self check

For questions 1 to 7, choose the letter that refers to the correct option.

1 Potassium hydroxide and sodium hydroxide are both:
- I bases
- II alkalis
- III soluble in water
- IV able to neutralise acids.

A I, II
B I, II, IV
C I, II, III
D I, II, III, IV

2 When the pH values of two solutions are 4 and 7 respectively, it indicates that the solutions are:
A acidic and basic
B basic and acidic
C neutral and basic
D acidic and neutral respectively

3 Which of the following indicators can measure pH values most accurately?
A litmus
B methyl orange
C phenolphthalein
D universal indicator

4 One of the following substances reacts with an alkali to produce a gas which has a pungent smell, turns red litmus blue and does not have any effect on blue litmus paper.
A hydrochloric acid, aq HCl
B ammonium tetraoxosulphate(VI), $(NH_4)_2SO_4$
C ammonia gas, $NH_3(g)$
D sodium hydroxide, NaOH

5 Distilled water has pH 7. After leaving it in air for three days its pH fell to 6.8. The following deductions can be made:
I. air has dissolved in the distilled water
II. the acid concentration of the distilled water has increased
III. the alkalinity of the distilled water has increased

A. I.
B. I, II
C. II
D. II, III

6 $Zn(NO_3)_2$ is the salt produced by the reaction of
I. $ZnCO_3$ and HNO_3
II. ZnO and HNO_3
III. $Zn(OH)_2$ and HCl

A. I only
B. II, III
C. I, II, III
D. I, II

7 Which of the following compounds will accept hydrogen ions in solution?
A. H_2SO_4
B. NH_4Cl
C. NH_3
D. NaCl

8 The main chemical in oyster and crab shell is calcium trioxocarbonates (IV). $CaCO_3$ is a salt and is only slightly soluble in water.
(i) Explain briefly why it is called a 'salt'.
(ii) State the method by which it can be prepared in the laboratory.
(iii) State the two solutions that can combine to form $CaCO_3$ in a preparation in the laboratory.
(iv) Write a balanced chemical equation to show how $CaCO_3$ will react with dilute hydrochloric acid.

9 A liquid chemical substance in the home is suspected to be acidic or basic:
(a) (i) Describe briefly to your parents a simple and safe experiment you would carry out to prove whether the substance is acidic or basic.
(ii) After carrying out the test in (a), give two properties of acids and bases.
(b) Name one substance used in everyday life which is:
(i) acidic (ii) basic (iii) organic and (iv) inorganic

10. (a) (i) Define an acid and a base.
(ii) Illustrate your answer in ((a) i. with a chemical equation.
(b) (i) Explain the term pH scale.
(ii) Give the range of a pH and explain its significance.
(c) Compare the pH of 0.1M CH_3COOH with 0.1M HNO_3.

11. (a) A group of students carried out a simple experiment to determine the pH values of some unknown solutions labelled **A**, **B**, **C** and **D**.
The pH values were found to be
A = 1.0
B = 4.0
C = 7.0
D = 13
If the labelled solutions were methanoic acid, distilled water, dilute hydrochloric acid and dilute sodium hydroxide, identify, with reasons, the solutions **A**, **B**, **C**, and **D** by the given pH values.
(b) Assign the colours that will be observed for each pH in (a) if a universal indicator were used.

12. (a) Hydrogen, carbon dioxide and ammonia were prepared by students in the laboratory from the following list of chemicals: zinc chloride, $ZnCl_2$; oyster shell, $CaCO_3$; Copper metal strips, Cu; lime, CaO; vinegar, CH_3COOH; ammonium chloride, NH_4Cl; magnesium ribbon, Mg; common salt, NaCl; dilute HCl.
(i) Write the formula of any two chemicals that could have been used to prepare each gas.
(ii) Using a table, indicate the tests, observations and deductions that can enable you to identify each of the gases.

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2 Soil conservation

Learning objectives

After studying this unit, you should be able to:

1 explain the principles of soil and water conservation
2 distinguish between macro and micro nutrients
3 state the functions of soil nutrients and their deficiency symptoms
4 describe methods of maintaining soil fertility
5 classify fertilisers into organic and inorganic
6 outline factors which lead to the depletion of soil resources.

Background information

Soils vary considerably in their physical and chemical properties. This is the result of variations in the nature of their parent materials and differences in the climate, relief and the vegetation of their areas of formation. The suitability of soils for different uses depends almost exclusively on these properties.

Agricultural soils, for example, should have a good balance of both physical and chemical properties, to make them fertile and productive. Such soils have nutrients, moisture and air for optimum plant growth and development. They must be conserved to ensure they can be used for sustainable agricultural production.

Principles of soil and water conservation

Soil and water conservation refers to a delicate combination of land use and management methods which protect the soil and its water from deterioration or depletion through natural and human-induced causes. The principles of soil and water conservation require that tillage and cropping practices, the use of manure and other soil treatments should safeguard the soil and its components for sustainable production of plants.

Various techniques, methods or strategies are employed to achieve these objectives, including techniques or methods of conserving soil moisture and maintaining soil fertility.

Conserving soil moisture

The roles of soil moisture in the cultivation of crops include:

- Absorption and use by plants in photosynthesis
- Dissolving soil nutrients so they can be absorbed and used by plants.
- Use in seed germination
- Maintaining plant turgidity and shape.
- Cooling plants through transpiration.

Methods of conserving soil moisture include:

- **Mulching** – this involves covering the surface of the soil with crop residues, dry grass, straw, etc. to drastically reduce the loss of soil moisture through evaporation. Mulches also enhance soil water infiltration into the soil.
- **Cover cropping** – cover cropping is the growing of broad-leaved leguminous plants on the soil to slow down the loss of soil moisture through evaporation, to reduce run-off and enhance infiltration.
- **Agro-forestry** – this is the integration of cropping with tree planting on a farm. It induces rainfall, maintains a high rate of water infiltration into the soil and improves the soil structure and its water-holding capacity.

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- **Minimal/zero tillage** – this leaves the greater part or the soil surface undisturbed. The undisturbed vegetative cover and the surface soil mulch conserve considerable amounts of soil moisture.
- **Soil conditioning** – this involves the use of soil stabilisers, such as lime and organic materials, to improve the structure of the soil and enhance its water-holding capacity.

Soil fertility and productivity

Soil acts as a reservoir (storehouse) of the mineral elements, water and oxygen required for optimum plant growth and development. **Soil fertility** is a measure of the nutrient-supplying ability of a soil. A fertile soil is one that supplies the right types of plant nutrients, for plant uptake and use, in the correct proportions, under appropriate conditions of soil pH and toxicity. **Soil productivity**, a much broader concept, is the overall crop-yielding capacity of a soil. It takes a suitable mix of soil fertility and physical conditions, such as the structure, texture and temperature of the soil, to make a soil productive. Soil fertility is only one of the attributes of a productive soil. For instance, a soil may be fertile but has poor texture, structure and temperature, so the nutrients cannot be absorbed and used by plants for growth. This may be a result of inadequate aeration or a lack of moisture to dissolve the nutrients. In a very loose-textured and badly-structured soil it may also be due to excessive loss of the nutrients through leaching.

Essential plant nutrients

A number of chemical elements are considered vital for the optimum growth and development of crop plants. They are considered essential because:

- they are directly involved in the physiological activities of growing plants
- lack of them causes abnormalities or injuries in plants, called deficiency symptoms, which can be used to diagnose the problem
- the deficiency symptoms can only be corrected by supplying the nutrient(s) that are lacking.

On the basis of the quantities required by crop plants for normal growth and development, these essential plant nutrients have been grouped into **macro-nutrients** and **micro-nutrients**.

Macro-nutrients

These are nutrients required by plants in relatively large quantities. Those obtained from the inorganic mineral and organic matter components in the soil are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Those obtained from air and soil water are carbon (C), hydrogen (H) and oxygen (O).

Carbon, hydrogen and oxygen are not commonly considered as macro-nutrients but they are, because they are the building blocks of carbohydrates, which constitute the bulk of plant tissue. Hence they are used by plants in large quantities.

Nitrogen, phosphorus and potassium are often supplied to the soil in fertilisers (see page xxx). They are also referred to as primary elements, because the fertilisers perform only the primary function of supplying them to the soil and nothing else.

Micro-nutrients

These elements are also known as **trace elements** and are required by plants in relatively small quantities. They are zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), cobalt (Co) and chlorine (Cl). If these elements are supplied to plants in large quantities, the plants show symptoms of poisoning and may die.

Other elements in the soil which contribute to the growth of plants in imprecise ways, but are not considered essential, include sodium (Na), iodine (I), silicon (Si) and fluorine (Fl). Table 2.4 lists some essential plant nutrients with details of their function and deficiency symptoms.

ACTIVITY 1 Identifying nutrient deficiency in plants

1 Your teacher will show you some pictures of plants that are deficient in certain nutrients.

2 *Work in groups* to identify and discuss the symptoms (use Table 2.4 to help you).

3 Classify the plants into those which are deficient in nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, manganese, molybdenum or boron.

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Table 2.4 Functions and deficiency symptoms of some selected essential plant nutrients

Nutrient	Function	Deficiency symptoms
nitrogen	a major constituent of plant protein; found in some other organic compounds associated with plant life	chlorosis (yellowing) of older leaves; stunted growth
phosphorus	required for respiration and metabolism; required for cell division because it is a constituent of nucleoproteins; required for seed germination, root development, seed and fruit formation; hastens maturation of crops and fruit ripening; strengthens plant structure against insects lodging	older leaves have purple/green colour; slender stems in grass plants; poor root and bark development; stunting of green parts of plants
potassium	catalyses most physiological functions; regulation of water; aids nitrate absorption from the soil; neutralises organic acids; strengthens plant straw and stalk against lodging, fungal and bacterial attack	chlorosis of leaves; marginal browning of leaves; curling of leaves; delayed maturity of plants
calcium	constituent of leaf lamina; aids growth process in the meristematic regions; corrects soil acidity; strengthens plant cell walls with calcium pectate; controls the toxicity of trace elements like Al_3^+, Mn_2^+ and Na_2^+ in plants; neutralises acidity in plants; helps in the translocation and storage of carbohydrates	difficulties in nitrogen absorption by plants; plant seedlings die; reduces soil cation exchange capacity
magnesium	constituent of plant leaf chlorophyll and therefore essential for photosynthesis	chlorosis of leaf veins (vein clearing); necrosis (death) of older leaves; stunted growth
sulphur	occurs in amino acids, hence it is a constituent of plant protein; influences protein synthesis, chlorophyll formation and biological nitrogen fixation	stunted growth; reduction in plant hormonal activities
manganese	regulation of oxidation–reduction reactions in plants; catalyst in chlorophyll activities	the top of young leaves show yellowish-green discoloration
molybdenum	nitrogen fixation through its influence in the plant enzyme system; metabolism of nitrates into amino acids and proteins	reduced nitrogen fixation; poor nitrogen transformation into plant protein
boron	regulation of various plant physiological activities	death of young plants; irregular spots on young leaves and buds; decreases the rate of water absorption and of the translocation of carbohydrates

Maintenance of soil fertility

Soils lose their fertility through crop removal, soil erosion, leaching and denitrification. Burning, an accepted method of farmland preparation in West Africa, causes the loss of non-metallic soil nutrients like nitrogen, sulphur and carbon, as they oxidise into gases that escape from the soil. Also, considerable amounts of nutrient-rich soil organic matter and beneficial soil micro-organisms are burnt off. This destroys the structure of the soil, making it more prone to erosion by both water and wind.

Farmers need to maintain the fertility of their soil. This involves maintaining the supply of soil nutrients at optimum levels for economic and effective crop production. Traditionally, soil fertility is maintained by practising shifting cultivation and land rotation. These two closely-related farming systems allow exhausted land to lie fallow until it regains its fertility through natural regeneration and nutrient recycling. However, the ever-increasing world population with its competing demands for the use of land have constrained the use of these traditional methods of maintaining the fertility of soil.

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More efficient methods, currently in use, include:

Cover cropping

The term 'cover crop' describes any broad-leaved crop that is grown to cover the surface of the soil while another crop is growing. Such crops also cover the land during off seasons.

Examples of cover crops are the species *Pueraria* and *Centroscema*. Cover cropping maintains soil fertility by:

- conserving soil moisture by drastically reducing evaporation from the soil
- smothering weeds, thus preventing the weeds using up nutrients
- fixing nitrogen in the soil
- preventing soil erosion
- regulating soil temperature to levels suitable for the mineralisation of organic matter by soil microbes
- providing a good source of soil organic matter through leaf fall/litter from the cover crops.

Green manuring

This usually involves growing leguminous crops and ploughing them into the soil at their flowering stage. While growing, leguminous green manure crops fix nitrogen in the soil and after turning them over into the soil, they become a source of soil organic matter.

Green manuring has the following benefits that:

- it prevents leaching
- it checks soil erosion and prevents nutrient loss
- it controls weeds, retaining the nutrients the weeds would have used for growing
- it reduces moisture through evaporation from the soil and promoting a better soil water-holding capacity through improved soil structure.

Crop rotation

This involves the growing of two or more crops one after the other on the same piece of land. It maintains soil fertility because different plants remove soil nutrients from different zones of the soil. Incorporating green manuring as part of the rotation of crops also helps maintain the fertility of the soil.

Application of organic/inorganic manures (fertilisers)

This involves the application of fertilisers to supply specific nutrients to the soil. It is done either as part of land preparation or as a cultural practice (see next section). Both organic and inorganic manures increase soil nutrient contents. Organic manures, in addition, improve the structure of the soil and regulate its temperature, leading to increased soil productivity.

Liming

Liming is the application of materials containing oxides, hydroxides and carbonates of calcium and/or magnesium to neutralise the soil or reduce its acidity. This makes most soil micro-organisms, especially nitrogen-fixing, mineralisation and nitrification bacteria, active so that these nutrients become readily available to plants. It also adds calcium to the soil and improves the soil structure, improving the water-holding capacity and soil aeration. Additionally, liming speeds up the decomposition of soil organic matter, the synthesis of humus and the release of fixed nutrients for plant use.

Control of soil erosion

Soil erosion depletes soils of nutrients. Controlling soil erosion ensures the retention of soil nutrients in the topsoil (see last section).

Fertilisers

A fertiliser is any solid or liquid material which is applied to the soil or plant to supply nutrient elements for plant growth. On the basis of their source, fertilisers are classified into organic and inorganic fertilisers.

Organic fertilisers

These are obtained from natural sources. They are used to increase the nutrient content of soils through organic matter mineralisation. They also increase the quantity of humus in the soil. Organic fertilisers (or organic manures) include compost, guano, green manure and farmyard manures. Farmyard manure is a collective name for the droppings of poultry, cattle, pigs, sheep and goats kept in pens.

The relative advantages of organic manures over inorganic fertilisers include their ability to improve

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both the fertility and the physical condition of the soil. They are relatively cheaper than inorganic fertilisers and supply both macro-nutrients and micro-nutrients. Organic fertilisers have a more lasting effect on soils because of the gradual release of their nutrients.

However, organic manures are difficult to transport because of their weight and bulk. They cannot be analysed to determine or quantify their nutrient content. This makes it difficult to supply the right types and quantities of nutrients to plants. They also sometimes contain weed seeds and disease pathogens.

Inorganic fertilisers

Inorganic fertilisers, also called chemical or commercial fertilisers, are manufactured from inorganic materials. They are applied to soils to give crops and other growing plants extra nutrients. Examples include NPK (nitrogen, phosphorus, potassium), urea, lime, sulphate of ammonia, superphosphate and muriate of potash. Chemical fertilisers mainly supply macro-nutrients.

Inorganic fertilisers are further classified into **single fertilisers** and **compound fertilisers**. Single (or straight) fertilisers normally contain only one macro-nutrient, for example urea (nitrogen), muriate of potash (potassium) and single or triple superphosphate (phosphorus). Compound fertilisers contain two or more macro-nutrients, with their relative percentages given by the fertiliser grade, for example NPK 15:15:15 (15% by volume of nitrogen, phosphorus and potassium; the remaining 55% is made up of filler material such as ground bone). Compound fertilisers that contain the full complement of nitrogen, phosphorus and potassium are described as 'complete' compound fertilisers; where only two of these fertiliser elements are present, such as in NPK 20:20:0, the compound fertiliser is described as 'incomplete'. There are also some four-face fertiliser grades, such as 20:20:10:2, where the last number designates magnesium. The main advantage of compound fertilisers over single fertilisers is that the nutrient requirements of the soil can be met with only one application of fertiliser. This saves energy, time and cost. Sometimes compound fertilisers are referred to as mixed fertilisers.



Fig 2.13 An example of an inorganic fertiliser.

Methods of fertiliser application

Several factors influence the application of fertilisers. Fertilisers should be applied when plants have developed enough roots to absorb the nutrients from the fertilisers. Fertilisers are best applied when the soil is neither too wet nor too dry. There should be just enough soil moisture to dissolve the applied fertilisers and to carry the crops to maturity. It is also important to apply fertiliser only after weed control. This will minimise the competition for the nutrients from weeds. The economic value of the crop also needs to be considered. Often, only crops that show good responses to fertilisers and those which sell for good prices will justify the cost of using fertilisers for their cultivation.

The chemical and physical conditions of the soil should also be considered. Knowing the nutrient content of the soil will help in the supply of the right type and quantities of fertiliser. The pH of the soil affects the availability of soil nutrients. Fertilisers should be applied when the pH is favourable, so as not to precipitate the fertiliser nutrients and make them unavailable to the plants. The soil texture will influence the frequency of application of fertilisers. Sandy soils, for example, are highly leached and may require more frequent fertiliser application.

The method of fertiliser application depends on the nature of the crop. Those with lateral root systems benefit from broadcasting of the fertiliser. However, plants with a dense leaf and branch structure could be damaged by broadcasting, because the leaves trap the fertiliser granules, causing burns and preventing the fertiliser getting into the soil.

Common methods of fertiliser application include:

- **Band placement** (banding) – the fertiliser is drilled 2.5–5.0 cm below, above or beside the seeds in

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bands. This makes it readily available to the roots of the seedlings.

- **Side dressing** – this entails feeding the fertiliser into the soil on one or both sides of crops growing in rows. This method is particularly useful for fertilisers containing very soluble nutrients, those applied to sandy soils or in areas of high rainfall, as it minimises nutrient loss by leaching.
- **Ring method** – this involves placing the right amount of fertiliser in a shallow furrow around each plant. The fertiliser is then covered. This method ensures that each plant receives the correct amount of fertiliser but it is labour-intensive and time-consuming.
- **Broadcasting** – this involves the uniform casting of the fertiliser granules on to the soil before, or just after, the crops emerge. It is usual to incorporate the broadcast fertiliser into the surface soil to ensure maximum nutrient uptake by plants. This method is quick but it is wasteful and encourages the growth of weeds.
- **Foliar application** – liquid fertilisers are often applied using this method. The liquid fertiliser solution is sprayed on to growing crops. In the absence of a sprayer, especially when growing crops on a small scale, a clean broom can be used to sprinkle the fertiliser solution on to the crops. This method takes its name from the fact that the fertiliser is applied to the foliage (leaves) of the crops. Sometimes fertiliser is applied to the crop in two or more doses at different times during the growth period. This is commonly referred to as **split application**. Additional doses of fertiliser, applied after the first dose, are called **top dressing**. Split fertiliser application meets the nutrient needs of certain crops at different stages of their growth and provides adequate amounts of fertiliser to crops in highly-leached areas.
- **Drilling** – in this method, the fertiliser is applied below the surface of the soil at the same time as seeds are being drilled into the soil (Figure 2.14). This special planter equipment has a component for seed sowing and another for drilling the fertiliser. The drilled fertiliser is usually placed slightly above the level where the seeds are placed.

Fertilisers can also be applied mechanically using a plough and various attachments such as distributors and spreaders.

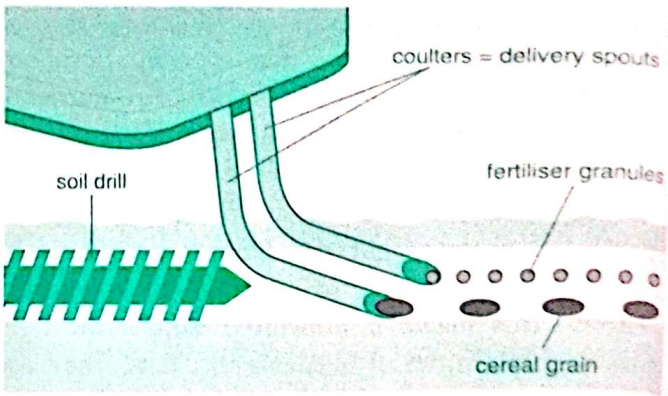


Fig 2.14 Fertiliser placed into drill beside seed at time of sowing.

Compost

The preparation of compost is referred to as **composting**. This is the process of promoting the biological decomposition of plant and animal materials by putting them in a heap or a pit where they can be properly compacted and moistened to give a fully or partially decomposed organic manure, called **compost**.

Compost is prepared using either the pit or heap (stack) method. The compost pit or heap should be sited near available composting materials and the garden where the manure will be used. A well-drained flat site under cool shady trees is best. This will check loss of plant nutrients through leaching and evaporation due to exposure to heavy rains and direct sunlight, respectively.

In both methods, the compost is built by creating layers of a starter and compostable materials to a height of about 1.5 m (heap method) or a depth of about 1.5 m (pit method).

Conditions necessary for composting

Successful composting depends on:

- **Moisture** – moderate moisture is required. A very low moisture content makes the materials too tough and hard to break down. Very high moisture content, on the other hand, results in poor aeration and slow decomposition.
- **Aeration** – compost heaps or pits should not be too compacted. This will ensure good aeration to increase the decomposition activities of the micro-organisms.

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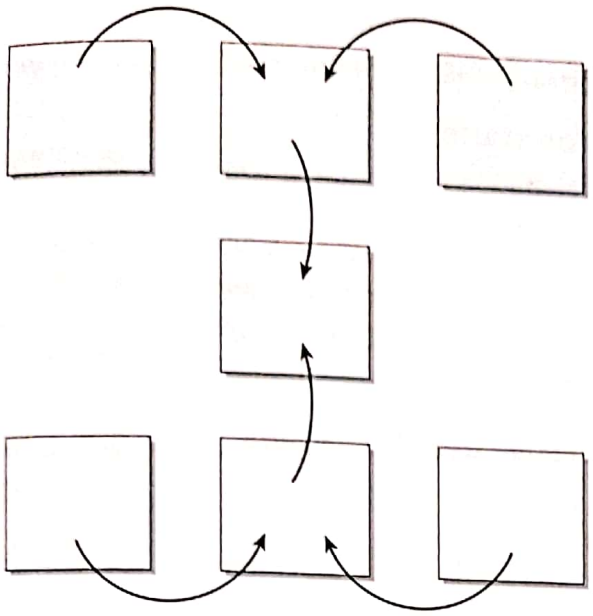


Fig. 2.15 Layout of compost heaps.

- **Micro-organisms** – decomposing bacteria and fungi should be available in good numbers to help decompose the compost materials quickly.
- **Temperature** – the temperature within the compost mass should be fairly high, to activate the micro-organisms to decompose the materials. Very high temperatures should be avoided, as this tends to kill the micro-organisms and stop the decomposition.

Preparing the Compost

The pit method is suitable for dry areas and the heap method for wet areas. The choice of method is to ensure the availability of moisture for the decomposition process.

Heap method

Lay out seven heaps, each measuring 1.2 m by 1.2 m with elephant grass walls 1.5 m high. See Figure 2.15

The process has three stages:

Stage I: Building the heap – Place pebbles, stones or split bamboo at the bottom of the heap to prevent water-logging. Place a 15 cm-thick layer of grasses and vegetable materials, followed by a 10 cm layer of starter materials (such as old compost or farmyard manure) to kick start the decomposition. Mix this layer with a nitrogenous fertiliser, soil and a liming material (for example ash) and sprinkle it with water to provide the conditions necessary for microbial activity and rapid break-down of the compost materials. This composite layer of the heap should not be too compact, to allow for good aeration and faster decomposition. Repeat th. layers until the heap is about 1.2 m high.

Stage II: Testing for decomposition – Drive a long stick, called a **tester,** into the heap from the side until it reaches the middle. Pull it out and feel it in the palm. If the stick feels hot, it means there is good decomposition but if it is cold it indicates that decomposition is not taking place, which calls for necessary corrective measures. The testing is done three to four weeks into the process.

Stage III: Turning – Turning the compost heap encourages good aeration, loosens compacted materials, allows the escape of carbon dioxide and removes excess moisture. All these help in rapid and even decomposition of the materials. Using a digging fork, turn heaps 1 and 2 into A and heaps 3 and 4 into B. Two to three weeks after the first turnings, turn heaps A and B into heap C. The prepared compost in heap C should be covered, shaded and stored until required for use.

The pit method uses the same processes and stages. The only difference is that in this method the compost layers are built in pits.

Freshly prepared compost should not be used immediately, as decomposition will still be ongoing. The release of heat during the decomposition can kill plant roots if the compost is applied to crops when fresh.

PROJECT

1 *Work in groups* to prepare compost and an earth box and use them to grow vegetables or flowers.

2 Keep a record of the procedures you use in a diary as well as how well your vegetables or flowers grow.

Depletion of soil resources

Besides soil moisture, the other important resources of a soil are its nutrients and its physical properties. These, together with the nutrients, determines a soil's **productivity.** The depletion (significant reduction or total loss) of these resources makes agricultural soils infertile and unproductive.

Factors which lead to the depletion of soil resources are:

Over-grazing

Over-grazing of either natural or artificial pastures exposes the soil to erosion and its effects and allows the evaporation of soil moisture into the atmosphere.

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Poor farming and tillage methods

These include land clearing through bush burning, ploughing along slopes instead of across them and continuous tillage of the land leading to the formation of hardpans and loss of soil structure. All these practices lead to considerable loss of soil moisture and nutrients.

Dumping of non-biodegradable waste on land

Waste materials are described as non-biodegradable if they cannot be decomposed by soil-dwelling organisms, particularly bacteria, under favourable soil conditions and over a considerable period of time. Such materials deprive soils of the benefits of their structure, namely, good aeration and water-holding capacity, better infiltration of water into the soil and water percolation within the soil. Such soils eventually become incapable of supporting plant growths.

Improper irrigation and drainage practices

Irrigation and drainage of farm lands improve soil resources, particularly soil moisture. They regulate soil moisture, ensuring that soils contain optimum amounts of moisture for plant growth and development. Irrigation supplements inadequate soil moisture; drainage removes excess soil moisture.

Improper irrigation and drainage practices could lead either to inadequate or excess soil moisture, both of which are undesirable. Over-irrigation could also destroy soil structure and cause excessive leaching of mineral salts, making soil acidic. Wrong (or unavoidable) use of water with a high salt content for irrigation may lead to soil salinity, a condition that seriously interferes with the growth of most plants. Over-reliance on overhead irrigation greatly increases the humidity of the farm environment and increases the incidence of crop pests and diseases that are common in humid conditions.

Surface mining and quarrying

Mining is the discovery, extraction and processing of valuable minerals. The extraction of minerals from surface soil is referred to as **surface mining** and **quarrying** is the process of forcefully removing large blocks, or broken pieces, of rock with the aim of extracting their minerals. Both surface mining and quarrying lead to the formation of pits and trenches on agricultural lands. The results include loss of rich topsoil, loss of soil vegetative cover, poor drainage and land wastage. The lost soil resources result in poor plant growth.

Deforestation

Deforestation is the wanton removal or destruction of tree-dominated vegetation from lands that are good enough for agricultural production. The practice leads to soil erosion, savanisation and even desertification, all of which deprive soil of agriculturally productive resources.

Excessive use of fertilisers

It is good agronomic practice to apply the right quantity of fertilisers to soils at reasonable periods and avoid excessive use. Excessive use of fertilisers leads to:

- soil alkalinity
- soil acidity
- soil salinity
- soil mineral toxicity, if fertiliser contains micro-nutrients
- reduction in population and activities of useful soil micro-organisms
- fixation and unavailability of some soil nutrients.

Soil erosion

Two important agents of soil formation, wind and water, are also responsible for the destruction of the soil through soil erosion.

Soil erosion is the wearing away of topsoil by water and wind.

Normal soil erosion is a natural process, in which the amount of soil lost through erosion is equivalent to the amount of new soil formed within the same time. Unnatural soil erosion takes place as a result of people's interference with nature, especially through bad management of farmlands and pasture. It is this type of soil erosion which we need to control.

Types of soil erosion

Detachment of soil particles, by the force of wind or water on the soil, and the subsequent moving and deposition of the detached soil particles by wind or

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water is the main mechanism of soil erosion. There are two broad types of soil erosion – wind erosion and water erosion.

Wind erosion

Soil erosion caused by wind is common in arid and semi-arid regions. These areas have poor vegetative cover and sandy soils or soils that have lost their cohesion through mismanagement. In these areas, fast-moving winds lift the soil off the land and blow it away in great clouds of dust.

Water erosion

In this type of soil erosion, moving water is the agent causing the problem. Water erosion is further classified into:

- **Splash erosion** – soil is detached by the impact of raindrops, which creates numerous depressions in the soil. The detached soil particles are not carried far, as in most cases the rainfall is not heavy enough to transport the soil particles.
- **Sheet erosion** – the uniform wearing-away of topsoil by a slowly-moving mass of water. It is not usually noticeable until the roots of plants become exposed (Figure 2.16a).
- **Rill erosion** – caused by water run-off from exposed land on gentle slopes. The run-off water joins the depressions or 'pot holes' created in splash erosion, creating small channels or 'rills'. These rills run down the slope of the land. The appearance of rill-eroded soil is very much like the surface of a corrugated iron sheet.
- **Gully erosion** – as rainfall becomes heavier, the rills are widened and deepened into gullies by fast-running run-off water. This is the severest kind of soil erosion (Figure 2.16b).

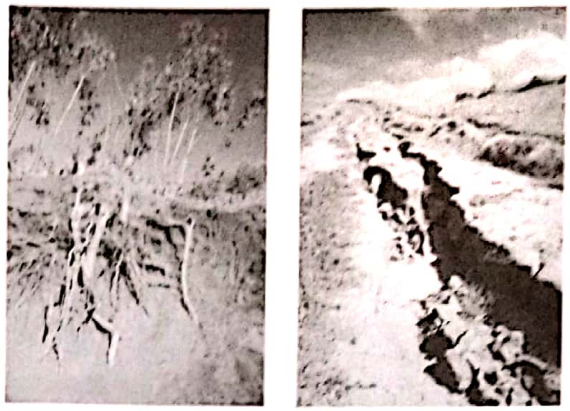


Fig. 2.16 Types of erosion: (a) sheet erosion, (b) gully erosion.

Effects of soil erosion

- Both wind and water erosion cause a loss of soil fertility.
- The roots of crop plants may be exposed and insects may lodge.
- Crops, farm structures and buildings are damaged by severe soil erosion.
- In gully erosion, the cultivable land area is reduced. Gully-eroded lands are difficult to cultivate mechanically.
- Rivers and streams which serve as sources of drinking or irrigation water may be silted up by eroded soil.
- Farmers and their livestock may suffer from eye and respiratory problems from the clouds of dust blown by wind erosion. The dust particles may cover the surface of crop leaves and impair their ability to absorb carbon dioxide and sunlight for photosynthesis.

Checking soil erosion

Soil erosion may be checked either by preventing its occurrence or controlling it once it is happening. Attempts at checking soil erosion are aimed at:

- avoiding soil detachment by breaking the beating force of raindrops or cushioning the force of raindrops or wind
- reducing the speed of run-off or wind
- enhancing the water infiltration capacity of the soil.

Mulching and cover cropping, for example, reduce soil detachment and movement. Soil erosion may be checked by enhancing the infiltration or absorption

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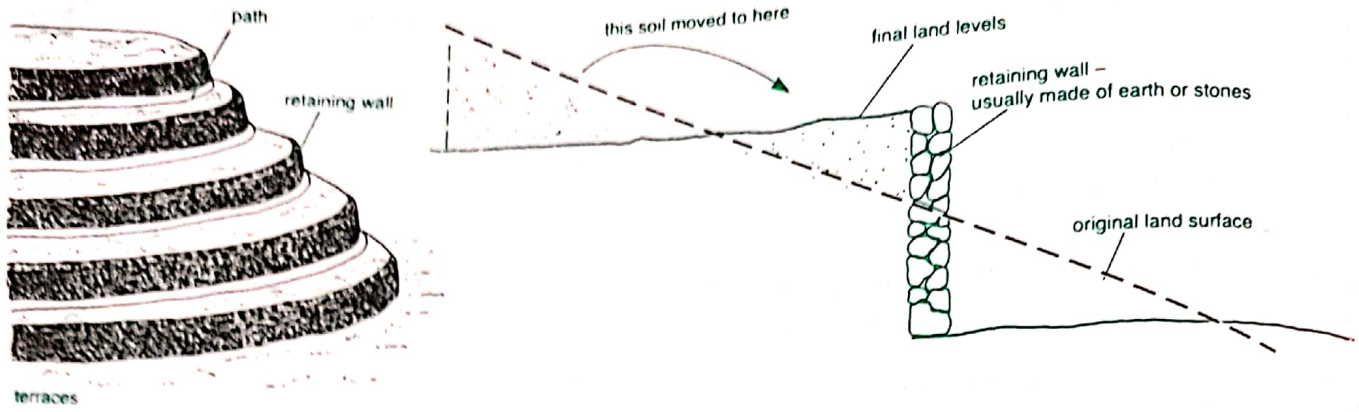


Fig. 2.17 Terracing.

capacity of soil through deep ploughing, increasing drainage or increasing the organic matter content of the soil.

Reducing the speed of run-off on or along slopes may be accomplished by strip cropping, contour ploughing and terracing:

- **Strip cropping** – this involves the alternation of strips of grass-covered ground and rows of crops, planted along the contours of the sloping land. It helps to slow down run-off by interposing barriers with high absorptive capacity.
- **Contour ploughing** – on steep slopes, the land should be ploughed along the contours and not down the slope of the land. The ridge-like contour bands reduce the speed of water run-off.
- **Terracing** – very steep slopes are cut into a number of level areas, which look like steps on the slope. These steps, or terraces, reduce the speed of run-off of water and check soil erosion caused by water (Figure 2.17).

Wind erosion is checked by:

- the use of windbreaks
- improving the structure and vegetative cover of the soil
- keeping the soil moist.

Windbreaks are rows of trees or shrubs planted at right-angles to the prevailing direction of the wind. They obstruct the wind and drastically reduce its speed and its soil particle lifting and transporting capacities. The effectiveness of windbreaks in checking wind erosion depends on the height and thickness of the trees or shrubs. When trees are similarly planted to check the damage to human habitation by wind, they are referred to as shelterbelts.

Self check

For questions 1 to 10 choose the letter that refers to the correct option.

1 One example of a soil micro-nutrient is
- **A** phosphorus
- **B** calcium
- **C** manganese
- **D** magnesium

2 A 100kg NPK (15:15:15) compound fertiliser has a filler make-up weight of
- **A** 30kg
- **B** 40kg
- **C** 45kg
- **D** 55kg

3 The classification of soil nutrients into macro-and micro-nutrients is based on
- **A** their solubility
- **B** the amounts required by plants
- **C** their sizes
- **D** the types of plants that use them

4 Purple colouration of older leaves of plants is a major deficiency symptoms of
- **A** Calcium
- **B** Nitrogen
- **C** Potassium
- **D** Phosphorus

5 Which of the following is a compound fertiliser?
- **A** Urea
- **B** NPK
- **C** Superphosphate
- **D** Muriate of potash

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6 Waterlogging in soils could be controlled through
- **A** Mulching
- **B** Irrigation
- **C** Drainage
- **D** Leaching

7 The severest form of soil erosion is
- **A** Sheet erosion
- **B** Gulley erosion
- **C** Rill erosion
- **D** Splash erosion

8 Which of these soil erosion control methods reduces slopes into steps?
- **A** Strip cropping
- **B** Contour ploughing
- **C** Terracing
- **D** Mulching

9 Which of the following factors does NOT deplete soil resources?
- **A** Soil erosion
- **B** Liming
- **C** Deforestation
- **D** Surface mining

10 Which of the following soil nutrients controls the toxicity of some micro-nutrients?
- **A** Calcium
- **B** Magnesium
- **C** Potassium
- **D** Phosphorus

11 What factors should be considered during fertiliser application? Describe three methods of fertiliser application.

12 What is soil erosion? Name three types of soil erosion caused by water. Describe four methods of controlling soil erosion.

13 **(a)** Name TWO green manure crops
(b) Outline four ways in which cover cropping maintains soil fertility.
(c) Distinguish between soil fertility and soil productivity

14 Distinguish between organic manure and inorganic manure and give three examples of each. Enumerate four methods of fertiliser application and discuss any two.

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3 Water

Learning objectives

After studying this unit, you should be able to:

1 describe the physical and chemical properties of water
2 distinguish between hard and soft water
3 demonstrate how to soften water
4 describe the steps involved in the treatment of water for public consumption.

Background information

Of all the millions of chemicals found on earth and its atmosphere, water is one of the few that humans cannot do without. Water is actually essential to all living things. The body mass of plants and animals is 50–90 per cent water. The Earth is unique in the solar system because of its abundance of water, which covers about 70 per cent of its surface (see Figure 2.18) – in oceans,

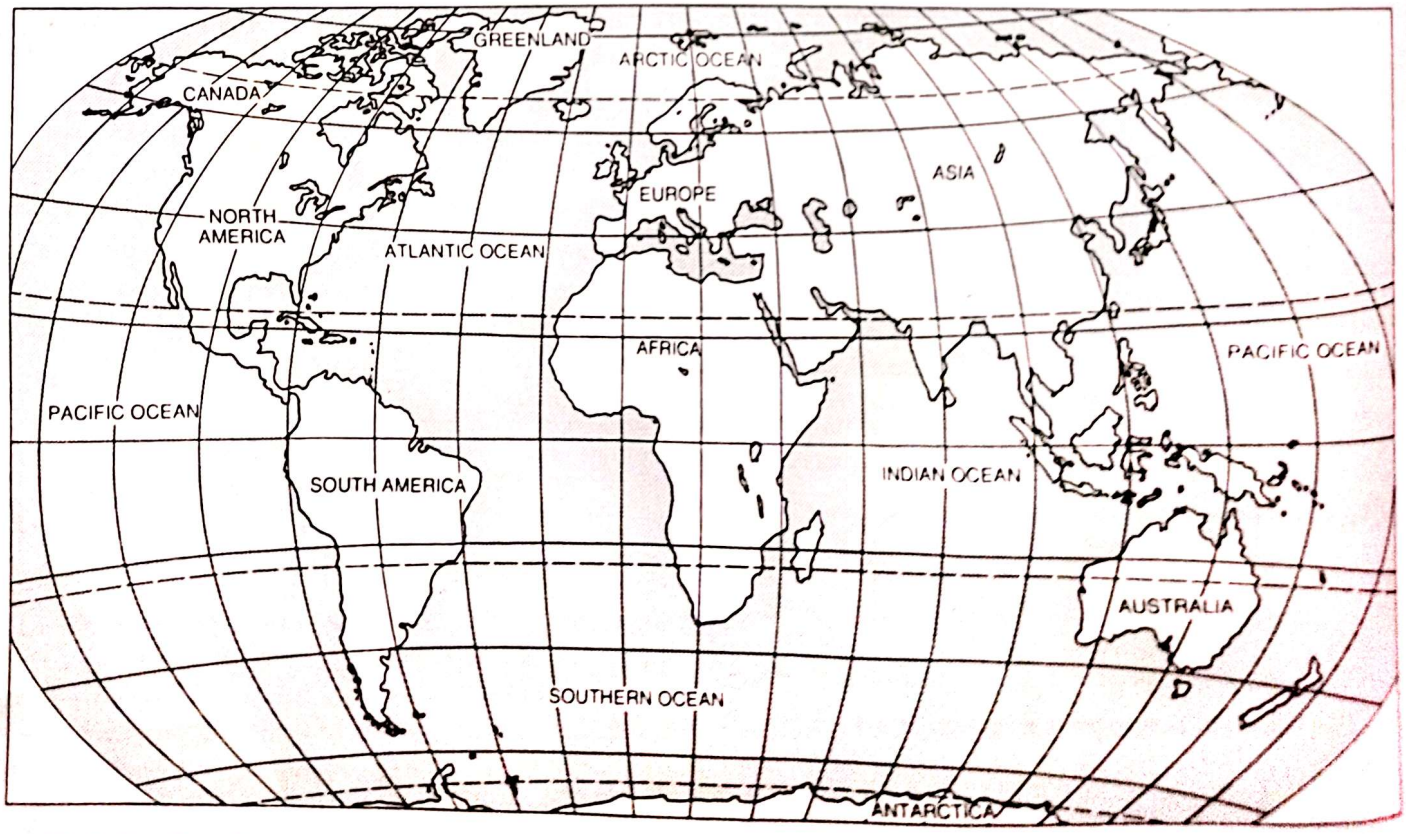


Fig 2.18 About 70 per cent of the Earth's surface is covered by water, much of which is locked up in ice at the poles.

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lakes, rivers, the soil and the atmosphere. Most living things would die without water, or in badly-polluted water, but flourish when the water conditions are right.

No other planet has yet been found that supports life. Humans depend on water to support life and for their social, commercial and industrial activities. Water has helped to shape the landscape of the Earth, for example through erosion. The effect of rain water, snow and frost on rocks gradually converts them into soil.

Throughout history, the growth of human settlements and civilisations has partly depended on the availability of water. For example, in Ghana, the discovery of gold in alluvial soils was due to the sifting and sorting action of water, which separates the denser gold particles from the less dense rock and earth (panning) (Figure 2.19).

Water is a strategic resource that needs to be treated or used wisely – both in its natural state and when it is harvested and used by humans. Careful and responsible use is necessary for the continued existence of life.

Water exists as molecules. Each molecule has the formula, H_2O; the properties and uses of water depend on its structure.



Fig 2.19 Gold panning.

The properties of water

Pure **water** is a clear, colourless and tasteless liquid.

At normal atmospheric pressure pure water:

- freezes at 0°C
- boils at 100°C
- has a maximum density of 1 g cm^{-3} at 4°C
- is neutral
- is a poor conductor of electricity (but becomes a good conductor when a small amount of an ionic compound is dissolved in it)
- expands between 4°C and 0°C and contracts (becomes less in volume) when melting from 0°C to 4°C so that, unusually, solid water (ice) *floats* on liquid water. Ice has lower relative density.
- has a high surface tension so that it appears to form a strong skin on its surface.

Dissolved solids, such as salts and sugars, raise the boiling point and lower the freezing point of pure water.

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ACTIVITY1 Determining the boiling point of water

1 Set up the apparatus as shown in Figure 2.20. Heat gently and boil for about two minutes.

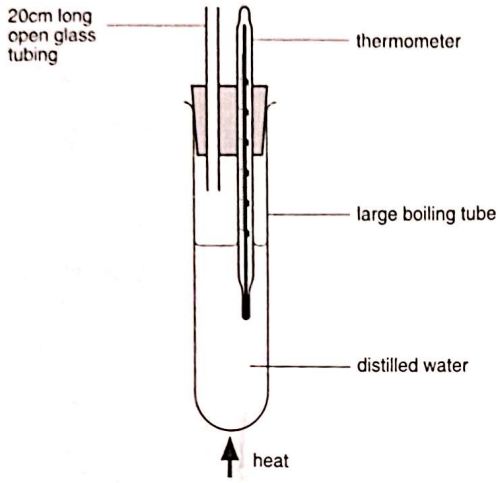


Fig 2.20

2 Read the temperature when the reading remains constant. Record it as the boiling point of water.

3 If the boiling point temperature is different from that expected, explain briefly.

Water as a universal solvent

Water has been described as the **universal solvent** because it is the commonest solvent and exists in the largest amounts. It dissolves many more substances than any other known solvent, some immediately and many over a longer period. Few substances have proved to be totally insoluble in it.

ACTIVITY 2 Investigating the presence of dissolved substances in water

1 Clean an evaporating dish or a watch glass.

2 Pour some tap water into the dish or on the watch glass.

3 Gently heat the water until all of it has evaporated. What is observed in the container after the evaporation? Explain your observation.

In Activity 2, concentric rings of dissolved solids are found in the dish after the evaporation. This should be repeated for water from a range of different sources to compare their solid content. Sea water, river water and rainwater could be used.

Tests for water

Useful tests for the presence of water are based on the colour changes when liquid water, or water vapour, is absorbed by two different salts.

White anhydrous copper(II) tetraoxosulphate(VI), $CuSO_4$, (copper sulphate) turns blue when it absorbs water, due to the formation of the pentahydrate salt, $CuSO_4.5H_2O$. The equation is:

$$\underset{\text{White}}{CuSO_4(s)} + 5H_2O(l) \rightarrow \underset{\text{blue}}{CuSO_4.5H_2O(s)}$$

Blue anhydrous cobalt(II) chloride, $CoCl_2$, turns pink or red when it absorbs water, due to the formation of the hexahydrate salt, $CoCl_2.6H_2O$.

$$\underset{\text{Blue}}{CoCl_2} + 6H_2O \rightarrow \underset{\text{pink or red}}{CoCl_2.6H_2O(s)}$$

Any water or aqueous solution of any substance will respond positively to these tests since they contain water. The tests indicate the presence of water but not its purity.

ACTIVITY 3 Demonstrating the solvent action of water

1 You are provided with samples of the following solids and liquids: sugar, starch, ethanol, vinegar, vegetable oil, salt, paper, rocks, wood, blood, charcoal, calcium hydroxide.

2 Put a 2.5 ml spoon of each solid into a boiling tube. Add distilled to a height of about 10 cm. Stir and swirl if necessary. Record whether it dissolves in the table below.

3 Pour about 4 cm^3 of each liquid into a boiling tube. Add about 8 cm^3 of distilled water to the liquid and swirl well. Add distilled water to a height of about 10 cm. Stir and swirl if necessary. Record whether it dissolves in the table below.

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Test	Dissolves completely, partly or not at all
Distilled water was added to the solid, stirred and swirled	
Solids	
sugar	
salt	
paper	
rocks	
wood	
blood	
calcium hydroxide	
charcoal	
Liquids	
ethanol	
vinegar	
vegetable oil	

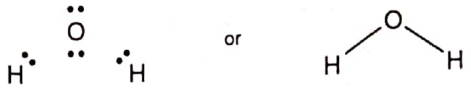
4 Explain briefly how substances dissolve or are unable to dissolve in water.

When a substance dissolves in water, an aqueous solution is formed. The water is called the **solvent** and the substance the **solute**. Some substances dissolve completely in water to form a uniform mixture, whilst others may not dissolve completely. In this case, the undissolved solute exists together with the aqueous solution of the dissolved part. Other solutes may not dissolve at all and are described as 'insoluble'. Some solutes take a longer time to be affected by water.

The nature of the water molecule

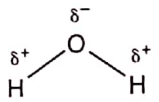
Water is a **covalent compound**. Two hydrogen atoms combine chemically with one oxygen atom to form it. Each hydrogen atom shares its single outer shell electron with the six outer shell electrons of oxygen. Both atoms thus acquire the stable (noble gas) electronic configurations and form a water molecule (see Figure 2.21).

X-ray crystallography and other experiments show that the water molecule has a bent shape. It also carries a small negative charge on the oxygen and a small positive charge on each hydrogen atom as shown in Figure 2.22.



- electron from hydrogen
- electron from oxygen

Fig 2.21 Structure of water molecule.



δ^+ slight +ve charge

δ^- slight –ve charge

Fig 2.22 Polar nature of the water molecule.

The shared electrons in the water molecule are pulled nearer to the oxygen which acquires a slight negative charge and the hydrogen acquires a slight positive charge. The O–H bond in water is described as polarised and water is therefore a **polar** molecule. The polar nature of the molecules explains many of the observed properties of water. The slightly negative oxygen end attracts and binds to the slightly positive hydrogen end of another molecule. This intermolecular attraction is called the **hydrogen bond**. It is strong and occurs between all water molecules.

Figure 2.23 shows hydrogen bonding between three water molecules. The inter-molecular forces are shown with broken lines. Note, however, that ionic and covalent bonds are far stronger than hydrogen bonds.

Because of this strong inter-molecular force, a high temperature is needed to separate the water molecules and convert the liquid into gas. Water therefore has a higher than expected boiling point (100°C) and evaporates slowly.

The same strong inter-molecular forces are responsible for the tough 'skin' or high surface tension

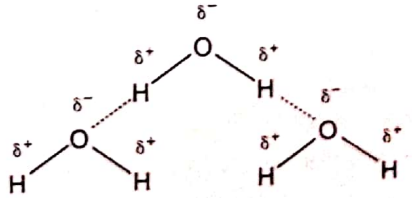


Fig 2.23 Inter-molecular forces (hydrogen bonds) between water molecules.

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of water. Some lightweight materials, such as leaves, straw, paper and flies and other small insects can be supported by this surface.

The polar nature of the water molecule is the reason why it dissolves many ionic and polar substances. The charged ends of the water molecules are attracted to oppositely charged ends in the solute. The water molecules, if they can, pull the particles of the other substance apart and mix with it, thereby dissolving it. If the water molecules are not attracted to the solute particles and/or cannot pull them apart, the solute will not dissolve.

ACTIVITY 4 To demonstrate the polar nature of water

1 Fill a burette with distilled water, as shown in Figure 2.24.

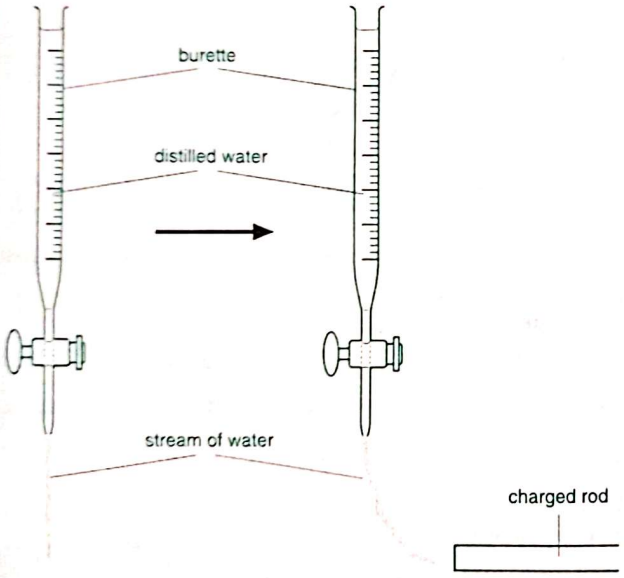


Fig 2.24 Demonstrating the polar nature of water.

2 Open the tap of the burette, to allow the water to flow out freely. Hold a plastic comb or an ebonite rod 4cm from the stream of water. Observe and record the direction of flow of the water past the comb or rod.

3 Rub the plastic comb or ebonite rod strongly on animal fur or your hair, to charge it negatively. Bring the charged rod or comb near the running stream of water; holding it about 4 cm away. Observe the direction of flow of the stream of water past the charged rod or comb. Which end of the water molecule is attracted to the negatively charged rod or comb? Explain.

4 Repeat step 3 but replace the rod or comb with a warm polythene rod or a warm glass rod rubbed well on soft tissue paper to charge it positively. Observe and record the direction of flow of the water past the glass or polythene rod. Which end of the water molecule is attracted to the positively charged rod? Explain.

5 What conclusion can you draw about the nature of the water molecules? Is water polar or non-polar?

Hardness of water

Water from most natural sources contains dissolved substances. Even tap water contains dissolved substances, some of which may have been added to serve specific health purposes. Some dissolved substances make water hard.

Hard water is water which does not lather easily with soap; the hardness is caused by the presence of dissolved calcium, Ca^{2+}, magnesium, Mg^{2+} or sometimes iron(III), Fe^{3+}, ions in the water. Water which lathers easily with soap is described as **soft water**. Soft water does not contain these ions.

When soap is used in cleaning, any calcium or magnesium ions in the water react with the soap to form an insoluble solid, called '**scum**'. Until all of these ions are removed as scum, the hard water will not lather. This explains why hard water will not lather easily with soap (Activity 5). It also explains why hard water wastes soap.

There are two types of hard water: temporary hard water and permanent hard water.

Temporary hard water

Temporary hardness of water is caused by the presence of calcium hydrogentrioxocarbonate(IV), $Ca(HCO_3)_2$, in the water. It is the calcium ions which cause the hardness. Temporary hardness is acquired when rainwater, containing dissolved atmospheric carbon dioxide, passes over or through rocks or soil containing limestone, calcium trioxocarbonate(IV), $CaCO_3$. The equation for the reaction is:

$$CaCO_3(s) + H_2O(l) + CO_2(g) \rightarrow Ca(HCO_3)_2(aq)$$

This is reversible – it can go in the opposite direction. Thus, when temporary hard water is heated, insoluble calcium trioxocarbonate(IV), $CaCO_3$, is formed as a white solid. The equation is:

$$Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + CO_2(g) + H_2O(l)$$

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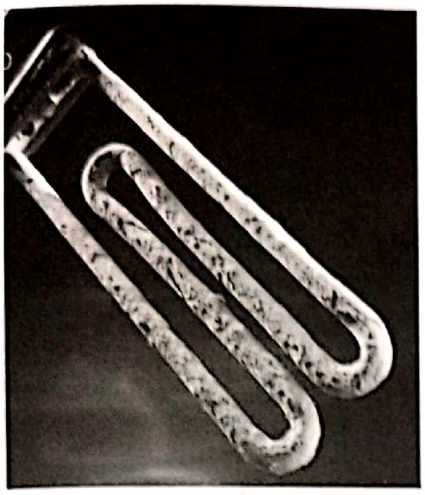


Fig 2.25 Heating element covered with scale.

This means temporary hardness can be removed by boiling.

The insoluble calcium trioxocarbonate(IV) in temporary hard water is a nuisance. It forms gradually in water pipes, toilets, kettles and other containers and is referred to as 'fur' or 'scale' (Figure 2.25). In kettles, the fur or scale reduces the heat conduction considerably, wasting energy and increasing costs. Furred or scaled pipes get blocked, reducing the flow of water.

In industry, temporary hardness may have to be removed, usually at a cost, to avoid the nuisance. In the home, kettle fur can be removed by washing the kettle with dilute mineral acid or a solution of an organic acid, such as ethanoic acid (vinegar).

Temporary hardness is caused by the presence of soluble calcium hydrogentrioxocarbonate(IV) in the water. It can be removed by boiling and filtering off the $CaCO_3$ deposit.

Permanent hard water

Some soils and rocks contain slightly soluble calcium (and magnesium) salts, such as calcium tetraoxosulphate(VI), $CaSO_4$. When rainwater flows over or through such soils or rocks, the calcium or magnesium ions dissolve or are leached into it and flow into water sources such as rivers, springs and the ocean.

Permanent hardness is caused by dissolved calcium, Ca^{2+}, magnesium, Mg^{2+} and iron (III) Fe^{3+} ions. It cannot be removed by boiling.

Permanent hardness can only be removed by chemical means, for example by using washing soda, sodium trioxocarbonate(IV), Na_2CO_3.

Advantages and disadvantages of hard and soft water

Hard water may be desirable for some needs and undesirable for others. The same applies to soft water. For example, hard water promotes good dental and bone growth in humans and animals but is a costly nuisance in industry, due to the cost of removing the hardness. Table 2.5 summarises the advantages and disadvantages of hard and soft water.

ACTIVITY 5 Investigating hard and soft water

1 Prepare a soap solution by dissolving 10 g of soap (sodium stearate) in 1 dm^3 ethanol–water mixture (500cm^3 ethanol: 500cm^3 distilled water).

2 Collect about 100 cm^3 of water from various sources, for example rain, sea, river, lagoon, pond, borehole and tap water. Measure about 25 cm^3 of each sample of water into conical flasks.

3 Pour the soap solution into a burette or graduated measuring cylinder.

4 a) Carefully titrate or pour the soap solution bit by bit from the graduated cylinder into each sample of water in the flask, swirling gently.
b) Record the volume of soap solution added to give a permanent lather.
c) Record any scum formed until the mixture forms a permanent lather.
d) List and explain which water is hard and which soft.

5 Boil each sample of water which is hard and repeat the activity. Which water is temporarily hard? Explain. Which water is permanently hard? Explain.

6 *Work in group* to investigate local sources of water and write a report of the ways hard water may affect the economy of your locality. You may include the effect on the soil and crops.

Softening hard water

The process of removing calcium, magnesium or iron(III) ions from water to enable it to lather with soap is known as **softening**.

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Table 1.3.2 Advantages and disadvantages of hard and soft water

Hard water		Soft water	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
has better taste due to dissolved salts – useful in the brewing industry	not suitable for dyeing and tanning because it prevents efficient reaction of chemicals	suitable for dyeing and tanning	not much taste
Ca^{2+} ions promote the development of strong bones, teeth and shells in animals	does not lather until hardness is removed which wastes soap	lathers well with soap, does not form scum, therefore saves soap	absence of Ca^{2+} ions causes weak teeth and bones and does not promote good growth in shellfish, crabs and snails
can be supplied in lead pipes or containers since lead does not dissolve in it to cause lead poisoning	forms scale in pipes, boilers, kettles, etc. this is a nuisance and increases costs	does not form scale in boilers etc.	dissolves lead from lead pipes and can cause lead poisoning
Ca^{2+} ions are used by plants to manufacture certain vital substances			
Ca^{2+} ions help in blood clotting in animals			
believed to reduce the likelihood of heart disease in humans			believed to increase the chance of heart disease

Generally, any process or action that can remove or separate these ions from hard water will soften it. Various methods are used.

Distillation

In distillation, water is boiled (vaporised) and the vapour cooled (condensed), back into pure water. Dissolved mineral salts, including those responsible for hardness, remain in the container in which the boiling takes place. The *distilled* water produced is pure. Distillation removes both temporary and permanent hardness.

Distilled water is suitable for preparing solutions in laboratories, diluting car battery acid and for the preparation of medicines. It is also used in boilers in industry, to prevent the formation of boiler scale and in some cleaning operations in hospitals. On a large scale, in industry, its production is costly and other cheaper methods of softening water, such as ion exchange are used.

Precipitation – addition of washing soda, limewater or caustic soda

The addition of washing soda solution, Na_2CO_3, to temporary or permanent hard water, removes calcium ions as insoluble calcium trioxocarbonate(IV), $CaCO_3$.

An aqueous solution of Na_2CO_3 is prepared. The solution of Na_2CO_3 is added to the water gradually, until no more precipitate of $CaCO_3$ is formed. The mixture is then filtered and the filtrate water is tested for softness. The equation is:

$$Ca^{2+}(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2Na^+(aq)$$

Boiling, and the addition of washing soda, as methods of removing hardness, are applied on a small scale in the home but are not used on a large scale in industry. Can you explain why?

A calculated amount of lime, **calcium hydroxide**, $Ca(OH)_2$, can be added to temporary hard water to precipitate $CaCO_3$, which can be filtered off. Care should be taken not to add an excess of lime, which would introduce extra calcium ions. The equation is:

$$Ca(HCO_3)_2(aq) + Ca(OH)_2(s) \rightarrow CaCO_3(s) + 2H_2O(l)$$

This method can be used on a large scale.

Caustic soda, NaOH, solution may also be used to remove the calcium and magnesium ions in the form of their insoluble hydroxides. The equations are:

$$2NaOH(aq) + Ca^{2+}(aq) \rightarrow Ca(OH)_2(s) + 2Na^+(aq) +$$
$$2NaOH(aq) + Mg^{2+}(aq)\ Mg(OH)_2(s) + 2Na^+(aq)$$

Ion exchange

As the name suggests, this is a method of removing the ions responsible for hardness by exchanging them

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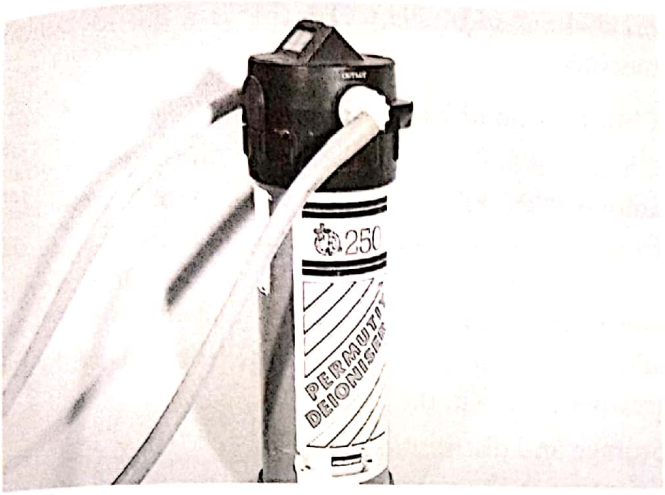


Fig 2.26 A modern ion exchanger for softening hard water.

for other ions, usually sodium, Na^+, ions which do not cause hardness. The method is also called de-ionisation or **de-mineralisation**.

A modern ion exchanger (Figure 2.26) contains a solid mixed-bed resin, for example **zeolite** (**permutit**). Many of the mixed-bed resins are organic resins made of plastic beads of polymers such as polystyrene, treated to absorb sodium ions. The resin may be mixed with activated charcoal.

The mixed bed is usually packed in a vertical column with a tap. The hard water containing the calcium and/or magnesium ions is poured on the column and allowed to wash through the mixed-bed resin for some time.

If the mixed-bed resin is represented as $(Na^+)_2Ex^{2-}$ the equation for the exchange can be given as:

$$Ca^{2+}(aq) + (Na^+)2Ex^{2-}(s) \rightarrow CaEx(s) + 2Na^+(aq)$$

After some time, the tap can be opened and a sample of the de-ionised water collected and tested for hardness.

The original resin can be regenerated by washing with hot concentrated aqueous hydrochloric acid, followed by sodium chloride solution. The sodium ions replace the calcium ions to obtain the original useful resin, $(Na^+)_2Ex^{2-}$.

Ion exchange is used on a small scale in the home, on a large scale in industry and in special situations, such as science laboratories. The treated water can be used for drinking, washing and very accurate laboratory experiments, for example cleaning in the semiconductor industry, battery acid water and many others.

Activity 6 Investigating the hardness of water of the locality

A team of students from two villages set out to find out the hardness of water in their villages. Samples of water were collected and tests conducted on them. The sample from one village was labelled **A** and that from the second village, **B**. The results of the tests were:

Tests	Observations	Inference
1. Soap solution was added to a sample of **A** and shaken.	The soap did not lather	(i)
2. An equal volume of soap solution was added to a sample of **B** and shaken.	The soap did not lather	(ii)
Samples of **A** and **B** were separately boiled well in a glass beaker and the tests continued	A white solid settled at the bottom of the container of **B** But there was no white solid at the bottom of container of **A**	(iii)
3. Soap solution was added to the boiled sample of **A** and shaken.	The soap did not lather	(iv)
4. Soap solution was added to the boiled sample of the **B** and shaken	The soap lathered	(v)

Answer the following questions:

1 Fill in the inference column in the table from (i) to (v). Explain your conclusions as to which one of the water samples is temporarily hard and which one is permanently hard.

2 Name the method you would use to remove the type of hardness in the water from village A and village B.

3 Which water will be best for promoting the growth of strong teeth in children? Explain your answer.

Purification of water – the treatment of water for public consumption

Water can contain substances other than those that cause hardness. These include suspended solid matter,

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dissolved salts and minute organisms, including bacteria.

Impure water is pumped from rivers, streams, lakes, dams and other water bodies into treatment plants or waterworks, where the raw water goes through a series of physical and chemical treatments to change it into safe, drinkable water for humans and for other purposes. The basic purpose of water treatment is to remove pollutants (things that cause the raw water to be impure or unsafe) and solid and dissolved substances such as mud and the eggs and larvae of some water organisms. Which stages are followed in which order depends on the source and type of raw water available.

Stages in large-scale water treatment

Filtration or screening

Large particles or fragments of organic materials are removed by passing the raw water through hard grey granite stones.

Aeration or bacterial oxidation

Exposure of the water to air kills some harmful bacteria and provides oxygen for micro-organisms, which degrade some waste products. One way of achieving this is to allow the water to fall over a series of short steps (a cascade). This process can also remove carbon dioxide, volatile oils and gases such as hydrogen sulphide, thereby improving the taste of the water.

Flocculation

Large suspended particles of organic debris, not removed by the first screening process, are brought together by agitation to form bigger clusters. These clusters are allowed to settle to the bottom.

Coagulation and sedimentation

Alum and/or polyelectrolytes are added to coagulate fine particles in the water. These are allowed to settle to the bottom by gravity or by a little agitation.

Filtration and precipitation or stratification

Most of the remaining suspended and dissolved particles are removed by passing the water through various strata of sand, fine stones, gravel and sometimes activated charcoal, to remove bad smells.

Chemical test and treatment

The pH is measured and adjusted to between 7 and 8.5 by adding calculated amounts of lime, $Ca(OH)_2$, or washing soda, Na_2CO_3. This is a quality control measure.

Chlorination or irradiation

Chemicals are added to release chlorine gas in small amounts to kill any remaining germs. Irradiation from radioactive sources may also be used to kill the remaining germs. This process is called **disinfection** or **sterilisation**. In some localities, fluoride ions, F^-, are added to promote dental health. This is usually the last treatment stage in the plant.

Storage and distribution

Scientists at the water treatment plant ensure that the final product satisfies safe levels of various dissolved ions for human consumption. The treated, safe water is pumped into storage tanks and then into pipes for distribution to the public.

Activity 7 Drawing a flow chart for the treatment of water for public consumption

1 Study the various steps involved in the treatment of unsafe water for public consumption.
2 Draw a flowchart for the treatment process for display in your class.
3 State two sources of water that can be treated in the way described in your flowchart

Smaller-scale water treatment methods

Where large-scale treatment of water for public consumption is not possible, water can be filtered and boiled for drinking. This kills most of the harmful bacteria that cause water-borne diseases (see Activity 8). Boiled water is safe for drinking but it is expensive and the method cannot be used to serve a town or a district – a lot of energy would be used when millions of litres of water are boiled.

ACTIVITY 8 Filtering water in different ways

1 Fold a filter paper and carefully insert it in a funnel; clamp the funnel to a stand as shown in Figure 2.27.
2 Stir some dirty muddy water and pour it slowly into the funnel containing the filter paper, collecting the filtered water (filtrate) in a beaker.

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- life processes in animals and plants
- domestic use
- industrial use
- energy production
- agricultural purposes.

ACTIVITY 10 Project: Investigating uses of water

1 Visit homes within the locality and list the various ways in which water is used. Take note of factors that can be considered as a waste of water. Suggest some ways in which the waste can be overcome.

2 Keep a diary of a day at home, noting roughly how much water you and your family use and what for.

3 Visit a local industry and find out how water is used.

4 Make a plan of an agriculture centre where water is used, or a vegetable growing centre in an urban area where water is used. Group the sources of water used under 'polluted' and 'clean'. List the possible effects of polluted water on any vegetables produced. Suggest solutions to the problem.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 The boiling and freezing points of water can change with a change in:
I density
II atmospheric pressure
III adhesion.
A I only
B II only
C I, II
D I, II, III

2 Treatment of water for public consumption can be done by:
I sedimentation
II filtration
III adding chlorine
IV distillation.
A I, II
B III, IV
C I, II, III
D I, II, III, IV

3 Which of the following compounds can cause temporary hardness of water?
A sodium hydrogentrioxocarbonate(IV)
B magnesium tetraoxosulphate(VI)
C calcium tetraoxosulphate(VI)
D calcium hydrogentrioxocarbonate(IV)

4 The scale formed in a kettle, after prolonged use, may be removed by adding
A ethanol
B hot water
C turpentine
D vinegar

5 Water is polar because it
A boils at 100 °C
B is attracted by charged materials
C falls by gravity
D contains oxygen atom in the molecule

6 Explain why water is said to be a universal solvent. How is this applied in:
a) the kitchen
b) the school science laboratory?

7 Describe a simple activity you would use to test the hardness of water. What are the advantages and/or disadvantages of hard water for:
a) people's health
b) water pipes
c) washing laundry?

Write down two ions present in hard water.

8 a) Why is it unsafe to drink untreated water?
b) List five causes of water pollution in your locality.
c) State six ways of preventing water pollution in the locality.
d) Describe briefly how water is treated on a large scale for supply to a township.

9 a) What salt is in the greatest concentration in sea water?
b) Explain why an ion exchange method will not be a good method of softening sea water.

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1 Water movement

Learning objectives

After studying this unit, you should be able to:

1 explain the causes of high and low tides
2 outline the effects of tidal waves.

Background information

If you go to the seashore and stay around for some time you will see that the level the water reaches on the shore regularly rises and falls. This is referred to as the **flow** and **ebb** of the sea. The flows are the rise and the ebbs the fall of the seawater levels. The regular rise and fall of water levels of oceans are the **tides**. Tides travel different distances up the shore, depending on their strength (Figure 2.29). Tides have puzzled humans for thousands of years, as far back as the fourth century BC. The first scientific explanation was given by Isaac Newton in the seventeenth century AD. He explained that tides are caused by the gravitational attraction (or pull) of the moon and the sun on ocean water. The moon is smaller than the sun but because it is nearer the Earth, its pull on ocean water is greater and hence its tidal effect is larger.

High and low tides occur daily and the highest and lowest tides occur twice a year. They repeat to create a cycle.

Tides

There are high tides and low tides. Two high tides occur daily, about 12½ hours apart, and are mainly caused by the moon. As the moon rotates round the Earth, at each place it is directly over, the moon exerts a strong pull on the ocean, creating a **tidal bulge** at that place and at the opposite side of the Earth (Figure 2.29b). This causes the ocean levels to rise, giving rise to high tides. Note that at the opposite side of the Earth the gravitational pull is stronger on the solid ground than on the surface water. In effect, the water tends to pull away from Earth's surface, creating the bulge. In other areas the pull is smaller and the tides are low.

The highest and lowest tides and moderately high and low tides occur twice a year, as the combined effect of the gravitational pulls of the moon and the sun are reinforced or reduced. At the first quarter and third quarter of the moon, the gravitational pulls of the moon and the sun are at right angles, which creates a smaller force of attraction for the ocean waters. This causes **neap tides,** which have moderately high and moderately low water levels at opposite sides of the Earth (Figure 2.29b). At the new and full moon, the gravitational pulls of the moon and the sun are in the same direction and act together, producing higher than normal tides, called **spring tides** (always called spring tides, even though they occur at other times of the year). During spring tides, the sea waves roll to the highest and lowest levels at opposite sides of the Earth (Figure 2.29b). At parts of the Earth where the tides are highest, rocks may be hidden in the rough tides and it is risky to swim near the beach.

Technological development has led to the use of tidal energy to generate electricity. When a large mass of water flows through a narrowing channel, such as an estuary or a bay, the funnelling process tends to accelerate the water but the mass of water at the front slows down, resulting in a wall of water that surges towards the channel. This is called a **tidal bore;** it increases the height of the wave and can be harnessed

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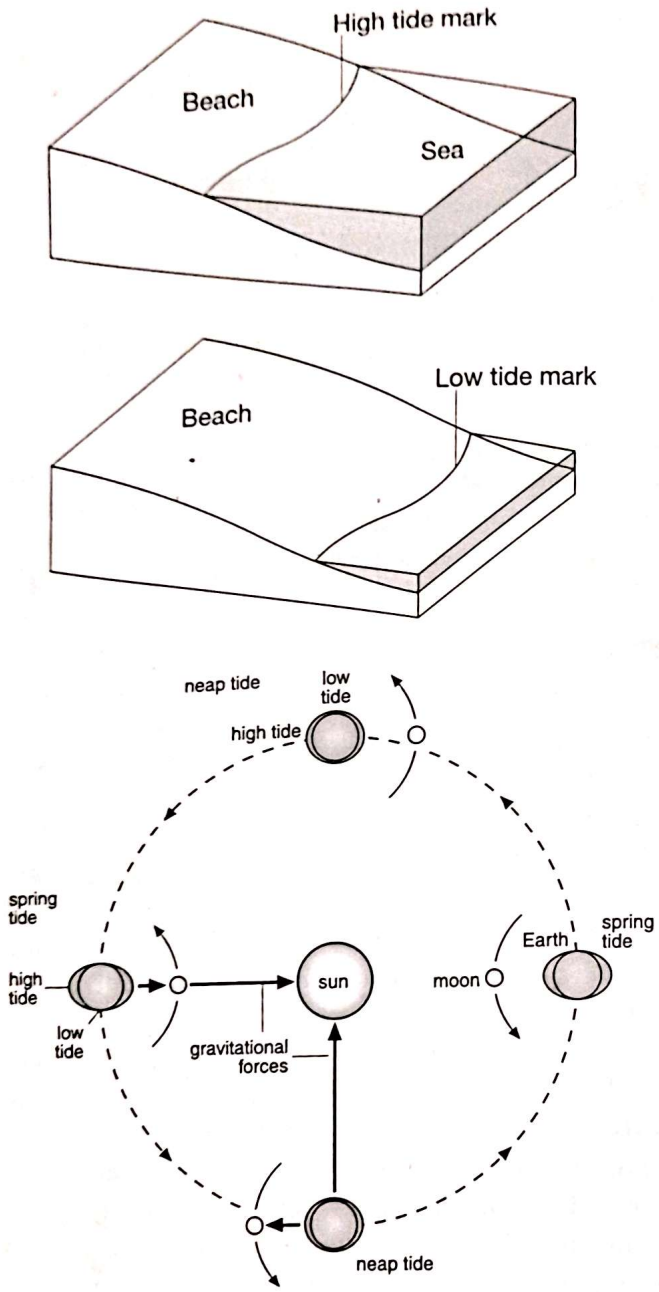


Fig 2.29 (a) High and low tide marks. (b) Tides are caused by gravitational pulls of the moon and sun on the oceans.

to generate electricity. There is a tidal bore at the mouth of the Qiantang Jiang estuary on the Hangzhou Bay in China.

A dam can be built to harness the tidal bore. High, incoming tidal waves, which carry a large mass of water, turn turbines and generate electricity. The trapped water is released when the tide ebbs, to generate electricity again.

The tides and the phases of the moon affect plant and animal life. For example, marine organisms that inhabit the inter-tidal zones (the regions between high tide and low tide) have evolved strong tidal and semi-lunar rhythms. These include the grunion fish, whose males and females spawn on the crest of spring high tides, and the fiddler crab.

Effects of tidal waves

Strong tides can cause erosion of coastal areas and destroy human settlements. Factors which may cause such effects include weak soil structure in the area, changes on nearby coastlines that may increase the strength of tides and human activities, such as sand extraction that reduce the protection for the coastline from strong tides. Coastal soil structures that are sandy and have no substantial rocky substructure tend to be easily washed away, especially in low-lying areas. This is believed to be the plight of some coastal towns in Ghana, such as Keta, Ada and Elmina.

The nature of tidal waves is one of the factors that affect fishing timetables and harvesting. Spring tides favour sport fishing.

Activity 2 Research on tides and tidal waves

1 *Work in groups* to reasearch tides and tidal waves using internet or textbooks.

2 Write a group report and present it to the class.

Self check

*For questions 1 to 5, choose the letter that refers to the correct option.

1 Which of the following factors contribute to tidal waves?
- I the gravitational force of the sun and moon on the sea
- II centripetal force created by the rotation of the Earth around its axis
- III the occurrence of cyclones

A I, II and III
B II and III
C I and III
D I and II

2 Which of the following can be used to generate electricity?
I tidal bore
II dams across running water
III solar energy
IV wind
A I, II, III and IV
B I, II and III
C I, III and IV
D II, III and IV

3 During neap tides, the direction of the gravitational force of the sun and the moon on the earth are in/at:
A opposite direction
B the same direction
C right angles or 90°
D 180°

4 During spring tides:
I The sun's gravitational force for the sea water is in the same direction as that of the moon for the sea water
II It is risky to swim in some beach waters
III The tides are higher than average
A I and II.
B II and III
C II only
D I, II and III.

5 The following are responsible for low and high sea tides:
A attraction of sea water by the sun alone
B reduced and increased attraction for sea waters at different parts on the earth's surface
C repulsion by both the sun and the moon for sea water at different parts on the earth's surface
D the short distance between the moon and the earth

6 Briefly describe the conditions that a technologist could utilise to produce electricity from tidal waves.
a) What is a sea tide?
b) In terms of gravitational forces of the sun and the moon, briefly explain the cause of neap tides and spring tides observed at beaches.

8 **a)** Why does the moon exert a stronger gravitational force on sea water more than the sun?
b) Suggest why there is more erosion by tidal waves at some coastal towns than others.

9 During the year, two lowest tides and two highest tides are observed on the beach of the ocean.
a) Explain how the lowest and highest tides occur
b) Suggest how these very high and low tides can affect fishing and buildings at or near the sea shoreline.

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2 The hydrological cycle

Learning objectives

After studying this unit, you should be able to:

1 explain the distribution of the Earth's water
2 explain the relevance of the hydrological cycle to plants and animals
3 outline the main sources of water contamination and its effect on humans
4 describe household water conservation methods.

Background information

Scientists believe water first appeared on Earth many millions of years ago, long before plant and animal life started, as vapour. Water vapour was one of the gases thrown out from volcanic eruptions. Later, when the Earth cooled, it turned into liquid oceans and other water bodies. Ocean or marine water became salty as water containing minerals from rivers and ocean floors flowed into it.

Water bodies found on the Earth's surface are known as **surface water** and those under the Earth as **groundwater**. The sources of groundwater are underground streams, springs, wells and aquifers. **Aquifers** are rock layers, often sandstones, that store water because groundwater flows into and through it. The total amount of groundwater is about twenty times more than the water in rivers and lakes.

Freshwater is water that is not salty.

Rainwater seeps or percolates through holes, porous soil and rocks into the ground. At a certain distance below the surface, the soil is saturated with water and the water no longer seeps. The level at which the soil is saturated with water is known as the **water table**. This saturated soil is about 8km underground.

Water sustains life and is circulated through the **hydrological** or **water cycle**. The water cycle is one of the natural cycles that provide a balanced system that serves plant and animal life and the environment. The stages in the cycle have served plants and animals constantly and well in carrying out various processes: some complex, some simple. The cycle is sometimes taken for granted. In our homes and other sources, it is only when the taps dry up that many realise water is indispensable to good health, sanitation and survival. The cycle regenerates water and therefore needs to be protected and not tampered with by humans.

Sources of water

Water is a very common substance in Ghana and other parts of the world. In hot deserts, such as the Sahara, water can sometimes be very scarce. In Ghana, a scarcity of water is common in the *Harmattan* season in arid (and some other) areas.

Sources of water include:

- the sea
- lakes and dams
- rivers, streams and rivulets (running water)
- springs
- wells (underground water)
- ponds and oases
- rainwater
- reservoirs
- pipe-borne, borehole or potable water.

Whether or not a water source is good for domestic use depends on the types of impurities in the water.

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Seawater and lagoons

The sea is the largest mass of water. It acts as a reservoir (container) or parent source into which all other forms of water flow. Seawater contains mineral salts, organic remains from sewage, dead organisms and plants and animals of different kinds.

The sea has a wide variety of other materials dissolved and suspended in it. Most of these substances get into the sea from rivers, streams and rain and from volcanic activity below the sea. Seawater is unsuitable for domestic use without treatment (including desalination).

Rivers

Rivers vary in their size and the rate at which they flow. The colour of the water depends on the nature and amount of suspended material. Naturally, rivers flow from high lands to low lands, into another river or into the sea. Some rivers have been dammed to become lakes. A dam enables the water supply to be controlled for domestic and agricultural purposes and also the generation of electricity through turbines, for example the Akosombo and Kanji hydro-electric power stations on the Volta and Niger rivers in Ghana and Nigeria.

Rivers contain dissolved mineral salts. Some rivers contain hydrogentrioxocarbonates(IV) of magnesium and calcium. Others contain sodium chloride, trioxonitrates(V) and ammonium salts. The chemical composition of a river depends largely on what is found in the bedrock over which the river is flowing and the rocks through which the rainwater trickled to reach the river. Rivers flowing over a hard bedrock will have less suspended matter than rivers that flow over a soft bedrock, as soft rock erodes more easily.

Human activities along the banks of rivers can change the content of the river water. Industrial waste and sewage residue, containing bacteria, can be carried along by a river. Polluted river water can be harmful to living things, especially if it is drunk untreated and pollution can alter the balance of plant and animal life in the rivers. Some rivers are sources of water-borne diseases, especially if human sewage is allowed into the river.

River water must be treated before drinking to avoid water-borne diseases.

Springs and wells

When rain falls, some of the water stands in pools, from which some evaporates, condenses and falls back as rain. Some rainwater also sinks into the ground through porous rock and collects on the hard rock underneath the soil. This underground water sometimes oozes out to form a pool or flows. It is called a **spring** (Figure 2.31). Some springs are hotter than others. In volcanic regions, springs (or geysers) throw up hot water. Spring water is often pure because it is filtered as it passes through the porous rocks.



Fig. 2.30 Mouth of a river (an estuary).

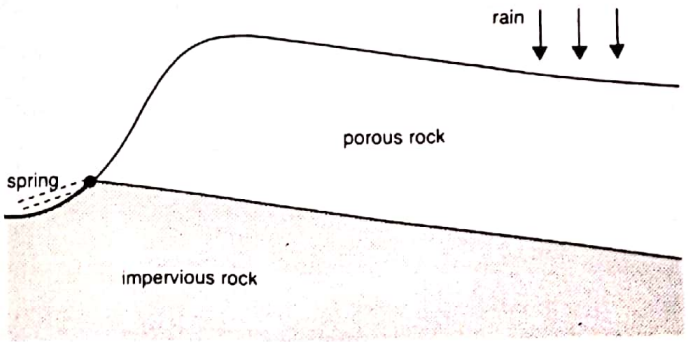


Fig. 2.31 Formation of a spring.

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Wells are often created by humans. These include boreholes and artesian wells. Wells are very important sources of water for humans, for shepherds' flocks and for other animals, especially in Northern Ghana. Wells serve as sources of drinking water for some villages. Boreholes with hand pumps are gradually taking the place of wells in Ghana.

Rainwater

Rainwater is one of the purest natural forms of water (unless the air is polluted). Rainwater (Figure 2.37) contains dissolved gases, particularly carbon dioxide, but this is not harmful. Rainwater for drinking can be collected and stored in barrels and clay pots in rural areas. Such storage containers must be washed clean before pouring water into them. A good cover prevents other pollutants from contaminating the stored water. Mosquitoes cannot breed on stored water that is covered tightly. If kerosene is poured on the surface of stored water, it prevents mosquitoes from breeding. However, the water becomes contaminated and very harmful to humans, so it is better to cover water properly rather than use kerosene.

Rainwater is the result of clouds cooling and precipitating into water as part of the natural water cycle. Clouds do not necessarily produce rain. Raindrops usually form around a 'freezing nucleus' which acts as a seed. Clouds can be seeded with chemicals sprayed from aeroplanes to start off the rainfall. In some countries, this is occasionally done to provide water for agricultural purposes.



Fig. 2.32 Rainfall.

ACTIVITY1 Demonstrating evaporation and condensation

1 Boil some water in a beaker.
2 Hold a piece of glass or a bowl with ice cubes in it over the boiling water about 30 cm away.
3 Describe what you see as the water vapour comes into contact with the cool surface.
4 Explain your answer, using the ideas of evaporation, condensation and water vapour.

The water cycle and plants and animals

The **water cycle** is the repeated natural circulation of water between the water sources on Earth and the atmosphere (Figure 2.33).

About 70 per cent of the Earth's surface is covered by water in oceans, seas, rivers, lakes and dams. The Sun warms the water, evaporating some of it into vapour which rises, by convection, into the atmosphere. Plants, including trees, lose water vapour through their leaves in the process of **transpiration**. **Respiration** of plants and animals also releases water vapour into the atmosphere.

The water vapour rises to the cooler parts of the atmosphere, higher up, where it condenses to form clouds. Clouds are tiny droplets of water suspended in air. Air and/or wind blows the clouds to higher and colder heights, where they are cooled further into larger water droplets. The cold, water-laden large droplets undergo large-scale **condensation** and fall to the ground as rain, dew, snow or hail. This is called **precipitation**.

Rainwater soaks through the soil, where some is absorbed by the roots of plants; some is transpired as

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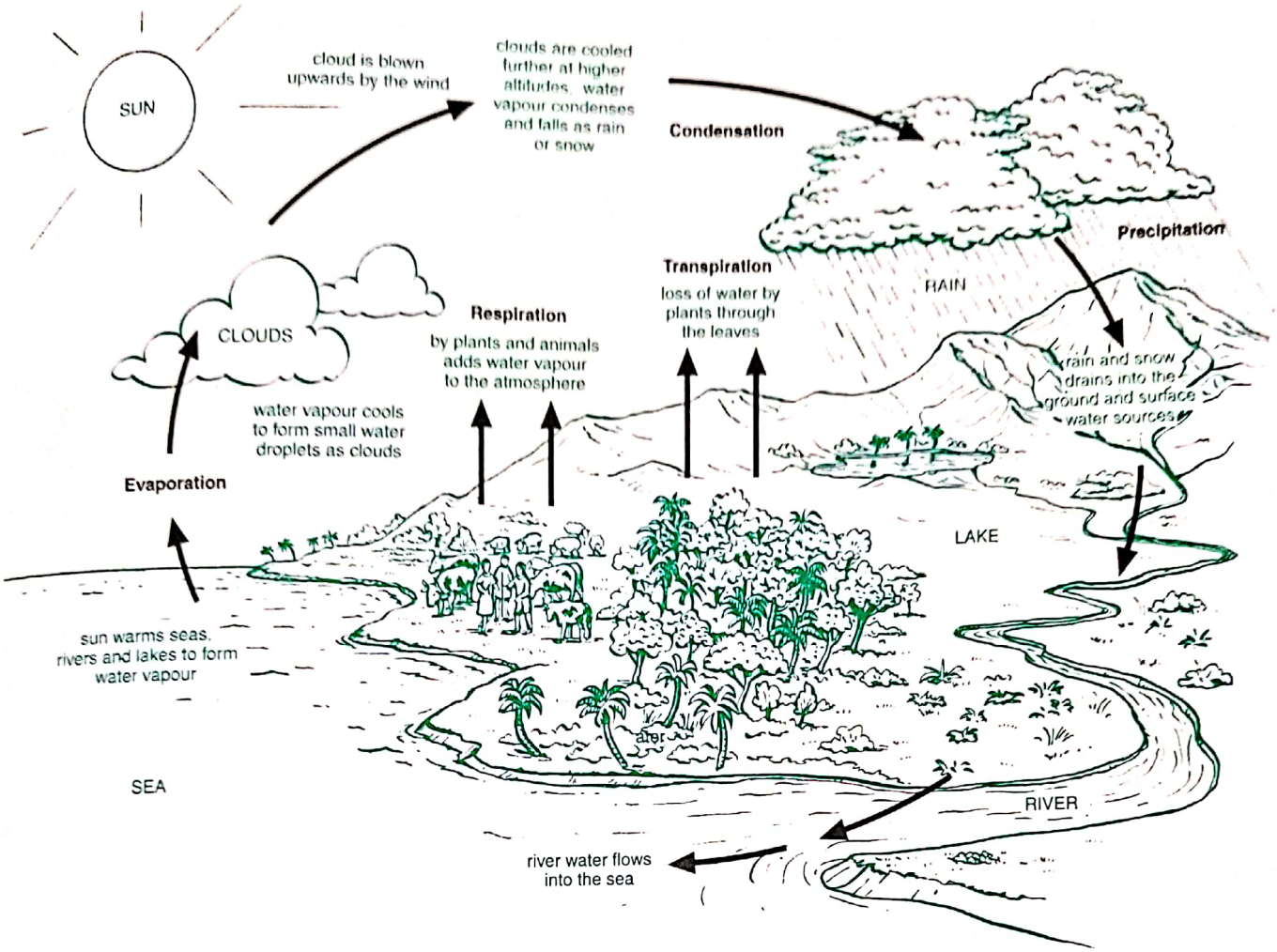


Fig. 2.33 The water cycle.

part of the cycle and some is used in photosynthesis. The remaining rainwater in the soil seeps through porous rocks into rivers, lakes, springs, etc. and finally into the seas and oceans. Some of the rain flows directly into these water sources, over the soil surface. At these water sources the evaporation starts all over again.

Humans and animals take in water directly by drinking it or indirectly in foods and release it into the atmosphere as water vapour, through respiration.

The processes that keep the water cycle running are:

- evaporation from water sources
- transpiration from leaves of plants
- respiration of plants and animals
- cooling and condensation of water in clouds into rain
- collection of rain water into the water sources and used by plants and animals to start the cycle again.

Water is a necessary part of plant and animal life. There is no substitute. Scientists are certain that plant and animal life started to evolve in water about 2.5 billion years ago and its continued existence still depends on water. Without water, there can be no plant and animal life on the Earth.

Water plays a crucial role in *plant* life. When it is absorbed through the roots, water:

- transports and distributes mineral nutrients for plant growth
- helps in the process of photosynthesis
- dissolves oxygen which makes it available to aquatic (water) plants and animals for respiration
- is transpired to sustain the water cycle.

In sunny conditions, a large tree can transpires as much as 300 dm^3 of water per hour through its leaves. Unwatered, seemingly dead, plants sprout again when

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rains begin. Deserts and deforested areas cannot sustain plant life except at oases.

Water is equally indispensable to *humans* and other *animals*. Water forms about 70 per cent (by mass) of the human body. Life activities and processes cannot take place without water.

Water is used by humans for:

- washing and cleaning
- drinking and indirectly in foods.

In the body, water acts as a:

- solvent to transport and distribute food nutrients
- solvent in which chemical reactions can take place
- liquid medium through which waste products are flushed out, for example urine and sweat
- means of keeping the body temperature cool.

An adult human needs about 2.5 dm^3 of water per day to sustain normal life. Some doctors recommend humans drink 3–6 dm^3 of water each day to improve body functions and give a longer, and better-quality, life.

Water contamination and related diseases

Some of the main sources of contamination of water are wastes created by human activity. When these wastes are not treated properly, they may end up in drinking water sources and pollute them. When humans and animals use the polluted water they may be afflicted by diseases and infections. This is the case in many rural communities which do not have sources of treated water.

Sources of waste include:

- **Domestic waste:** food remnants and chemicals, for example disinfectants and paints
- **Trade waste:** market and street vendor refuse
- **Industrial waste:** waste from factories, mainly chemicals produced or used
- **Agricultural waste:** chemicals used in farming, for example pesticides, herbicides and inorganic fertilisers such as ammonium trioxonitrates(V)
- **Radioactive waste:** hazardous radioactive products from nuclear power stations and facilities that manufacture nuclear weapons
- **Special waste:** such as hospital waste (blood and tissue soaked materials for example bandages and knives).

The diseases that may arise from these waste hazards can be:

- **Water-borne** – for example cholera and typhoid
- **Water-washed** – for example cancer (radioactive waste), neurological diseases or Minimata disease (mercury poisoning)
- **Water-based** – for example bilharzias (schistosomiasis)
- **Insect-based** – for example malaria and tsetse fly.

Conservation of water

To conserve water is to protect it, use it carefully and to sustain it. It means using water efficiently and wisely, not wasting it and keeping reserves for use during times of scarcity or shortage.

It is necessary to conserve water: there can be no life without water. The world population is growing and activities that need water are increasing, resulting in higher costs of production of water per person.

Conservation starts in the home, where water is used for flushing toilets, washing, drinking, cooking and gardening. Using treated water prevents infection by diseases carried in untreated water. The industrial use of treated water is on a larger scale: in production processes, for example beer-making, in general cleaning and in the operation of boilers and cooling systems. Domestic use competes with industrial use; in both places, there is a need to conserve water.

Even more important is the conservation of water in its natural source, because treated water comes from those natural sources. If water from the more accessible natural sources is not conserved, having to obtain it from the sea or from more inaccessible sources, such as deep aquifers, will be more costly.

Awareness of wastage and the practice of good conservation methods helps conserve water.

The pipe-borne water received in the home has been treated, which costs money. In the home, water is wasted in activities such as bathing and washing. Every person should make a conscious effort to minimise the water they waste, to conserve water for the whole

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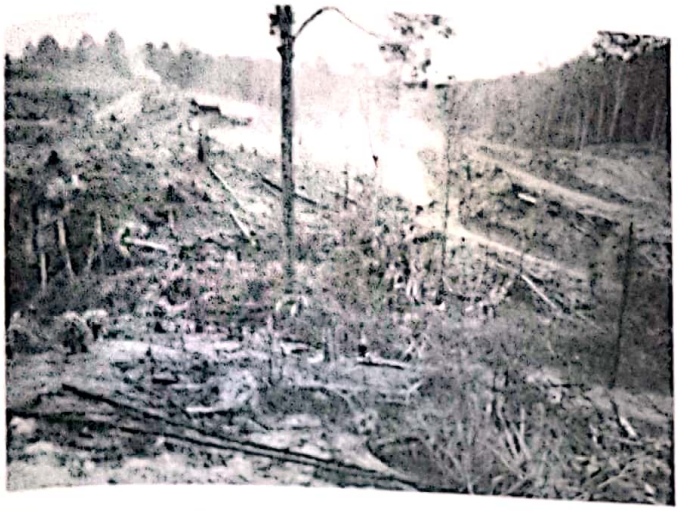


Fig. 2.34 Deforestation.

community. Water leaks in homes should be quickly repaired.

Spillages from water pipelines can be avoided by an efficient, modern monitoring system. Damage to pipes and taps wastes treated water and costs the nation a lot of money. Children who play with public pipe-stands waste a lot of treated water. Damaged taps should be reported to the nearest Ghana Water Company post for repairs.

Deforestation (Figure 2.34) reduces transpiration and affects the water cycle. Population pressure and greed encourages 'slash and burn' farming and other development methods which lead to deforestation. Public education and the making and improving of laws to check deforestation would certainly help to improve the balance, as would re-forestation programmes.

Ways in which treated water is wasted

Treated water is wasted through

- burst and leaking public supply pipes
- leaking taps in the home
- excessive use or over-use, for example in bathing, water closets, gardening and washing and cleaning in general
- agricultural use (agriculture needs water more than in the domestic sector but **not** treated water).

Ways in which domestic water can be conserved

- Education on the economic, wise and efficient use of water.
- Checking, stopping and reporting of leaks in the supply systems and in the home.
- Harvesting and storing of rainwater for use and as back-up for treated water.
- Keeping reserve storage systems, for example underground pots and tanks or overhead tanks.
- Minimising or efficient use of water in gardening, for example in maintenance of lawns, flowerbeds and vegetable beds.

Safe water storage

Wells are often created by human activities. These include bore holes and artesian wells. Wells are very important sources of water for humans and for shepherds' flocks as well as for other animals, especially in Northern Ghana. If the well is deep the water is usually safe to use. Water from shallow wells should be boiled before use as it may be contaminated by sewage. Wells can also serve as sources of drinking water for some villages. Bore holes with hand pumps are gradually taking the place of wells in Ghana today.

In towns and cities water sources are often contaminated so the water is piped to special treatment plants where it is purified and made safe to use. Is is then piped into the home.

Rainwater is one of the purest natural forms of water (unless the air is polluted). Rainwater contains dissolved air, particularly carbon dioxide, but this is not harmful. Rainwater is collected and stored in barrels and clay pots in rural areas for drinking. The containers are washed clean before pouring water into them. A good cover prevents other pollutants from contaminating the stored water. Mosquitoes cannot breed on stored water that is covered tightly. If stored rainwater is mixed with kerosene to prevent mosquitoes from breeding, the water becomes contaminated and very harmful to the body, so it is better to cover water properly rather than use kerosene.

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ACTIVITY 2 Project: collect and analyse national population and water consumption figures

1 Visit, or write to, the Ghana Population Council, Ministry of Health, Accra to obtain the following information: the population of Ghana every five years from 1960 to 1995 and the percentage annual population growth rate. Where figures are not available for every five years, use the annual growth rate to calculate them.

2 On graph paper, plot the population on the vertical axis against the year on the horizontal axis. From your graph, estimate Ghana's population in 2005 and 2010.

3 Visit, or write to, the headquarters of the Ghana Water Company to find the national water consumption per year for every five years from 1960 to 1995.

4 List the figures in a table like the one below.

Year	National water consumption/kg

5 **a)** On graph paper, plot the annual water consumption on the vertical axis against the year on the horizontal axis.
b) Comment on the trend on the consumption of water over the period.
c) Suggest two reasons for the trend in consumption.
d) Predict what the national demand would be in 2005.

6 Does the trend and the conclusions you can draw from the population and water consumption graphs apply to your village, town, city or community? Discuss briefly.

ACTIVITY 3 Design a water harvesting technique or domestic water reuse system

1 *Work in groups* to discuss and design a simple water harvesting technique or a domestic water reuse system.

2 Present your design to the class.

Self check

For questions 1 to 5, choose the letter that refers to the correct option

1 Which of the following sources of water is not directly linked to the sea?
A Rivers
B Streams
C Lagoons
D Ponds

2 Rainwater that passes through porous rock settles on the bedrock. Sometimes it oozes out and flows. This is called a:
I rivulet
II well
III spring
IV oasis
A III only
B I, II
C I, II, III
D I, II, III, IV



Fig. 2.35

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3 Which of the following processes does not contribute to the water cycle?

A Evaporation of sea and soil water
B Deforestation
C Running water into sea
D Rainfall

4 Which one of the following methods or processes is not suitable for preservation of water?

A Keeping a reserve water source
B Prevention of pollution
C Using a minimum of treated water to bathe, wash and clean
D Irrigation

5 Which of the following are sources or processes by which water can get contaminated?

I Burning fuels containing sulphur
II Allowing domestic waste to flow into rivers
III Using organic manure
IV Using inorganic manure
A I, II
B I, II, III
C II, III
D I, II, IV

6 Write down two sources or processes each by which water can be:
a) contaminated
b) protected from contamination.

7 A rough sketch of the water cycle, showing the main processes, is shown in Figure 2.35. The letters A, B, C, D and F represent sources of or storage systems for water. Write down the names of the sources A, B and C and the storage systems D and F.

Can the water cycle operate without the sun? Explain.

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1 Excretory system

Learning objectives

After studying this unit, you should be able to:

1 explain the meaning of excretion
2 identify organs of the excretory system and their products in mammals
3 talk about some disorders of the urinary system in humans and their remedies
4 state the excretory products of flowering plants and explain how they are excreted.

Background information

Living organisms use energy in their bodies, to carry out their life activities. This energy comes from organic food substances. These food substances are broken down in the body cells in a chemical process, respiration, during which the energy is released (see page 93). Other chemical processes occur in the cells and produces substances which are used to build up the bodies of living organisms.

Metabolism is the name given to the many hundreds of chemical reactions going on inside each of our cells. It is used to describe both the breaking-down processes (catabolism) and building-up processes (anabolism). During metabolism, useful and harmful products are produced. The useful products are used in the body while the harmful ones are eliminated from the body cells.

It is important that the harmful substances are eliminated, because their presence will disturb the proper functioning of the cells. Many are also toxic (poisonous). The harmful substances are referred to as waste metabolic products and their elimination from the body or cells of living organisms is termed 'excretion'.

Plants do not have an elaborate excretory system like animals, because they manufacture their own food in a form and quantity they can use directly. They produce very few waste metabolic products and so do not need special excretory organs.

What is excretion?

Excretion is the removal of the waste products of metabolism from the body or cells of living organisms. It must not be confused with **egestion**, which is the removal of the waste products of digestion as faeces and **secretion**, which is the production and release of useful chemical substances.

Simple organisms (for example unicellular organisms) excrete by diffusion through the cell membrane. Larger, multicellular organisms take in complex organic food substances which they digest, absorb and assimilate, producing large quantities of waste metabolic products in the process. Animals also take in certain substances that they do not want or cannot use, substances which cannot be stored in the body (such as vitamins and proteins), or poisonous substances.

Intestinal bacteria and other pathogens produce unwanted substances. The break-down products of worn-out cells, for example red blood cells, are not useful to the body. Certain chemicals produced by the body are no longer needed once they have completed their functions and drugs such as alcohol must also be excreted from the body.

Animals have therefore developed special organs for excretion. These organs and the structures

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associated with them form the **excretory system**. This system removes toxic substances and prevents their accumulation in the animal's body.

Excretory organs

Mammals have four main excretory organs:

- The **lungs** remove carbon dioxide and water from aerobic respiration (see page 93).
- The **liver** removes bile pigments from the break down of haemoglobin in worn-out red blood cells (see page 115) which are lost in the faeces.
- The **kidneys** remove water and large quantities of urea, a compound containing nitrogen, made by the liver from excess amino acids in the process of **de-amination**.
- The **skin** removes salts, water and traces of urea via the sweat glands.

The mammalian urinary system

Two **kidneys** are connected to the urinary bladder by two **ureters**. A tube, the **urethra**, leads from the bladder to the outside. The kidneys have a very rich blood supply through the renal arteries, which lead from the dorsal aorta. The renal veins leave the kidneys before leading into the inferior vena cava (Figure 2.36).

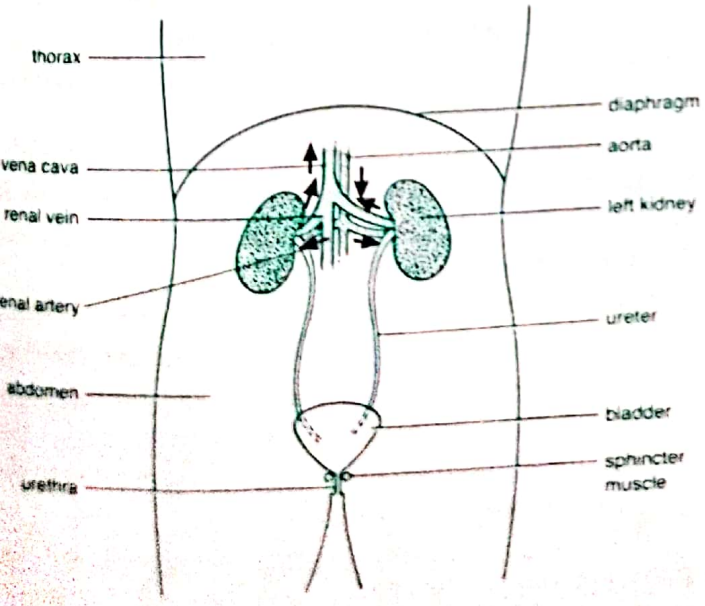


Fig 2.36 Human excretory system.

ACTIVITY 1 Observing the urino-genital system of a small mammal

1 Examine a small mammal which has been dissected by your teacher to display the urino-genital system.

2 Draw and label the dissection, using Figure 2.36 as a guide.

Kidney structure

Two main regions can be seen in a vertical section of a kidney – a darker, outer region, the **cortex** and a lighter, inner region, the **medulla**. The cortex is surrounded by a tough capsule. The base of the ureter is enlarged and forms the **pelvis** and the inner border of the medulla is rigid, forming the **pyramids** (Figure 2.37).

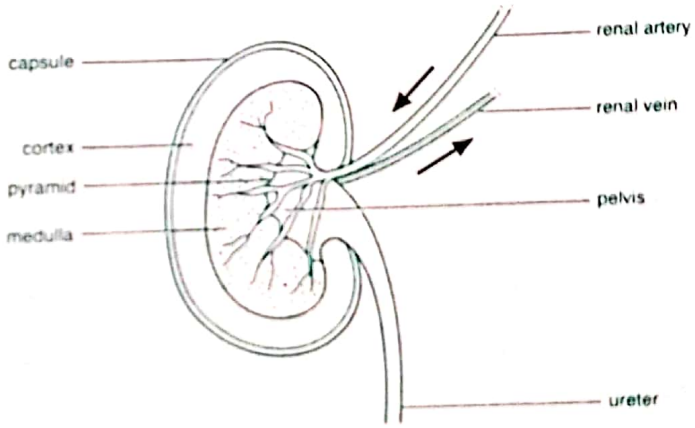


Fig 2.37 Vertical section through the kidney of a mammal.

The **kidney tubules** (also called nephrons) are the basic units of the kidney. There are about one million of them per kidney. Each consists of a **Bowman's capsule** leading into the **first coiled (proximal) tubule**, then to the **loop of Henlé** and the **second coiled (distal) tubule**. Finally, a number of tubules join into a **collecting duct** which enters the pelvis via a pyramid. Bowman's capsule and the coiled tubules are in the cortex, whilst the loop of Henlé is in the medulla. Inside the Bowman's capsule is a network of capillaries, the **glomerulus**. A branch of the renal artery leads into this and branches of the renal vein leaving the glomerulus and capillaries surrounding the tubule eventually drain into the renal vein (Figure 2.38).

Kidney functioning

Blood carrying urea enters the kidney through the renal artery. As the branch of the renal artery (afferent

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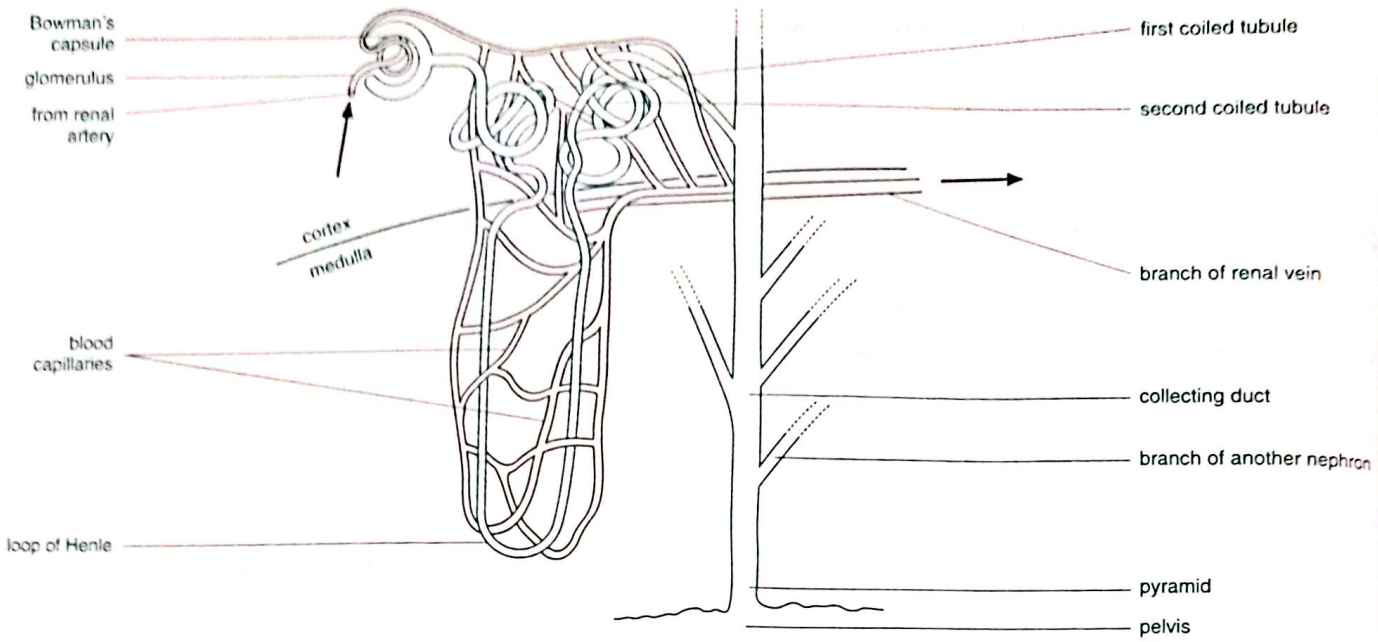


Fig 2.38 Diagram of a kidney tubule and its associated blood vessels.

arteriole) entering the glomerulus has a *larger* diameter than the efferent arteriole leaving it, pressure builds up. The capillaries of the glomerulus and the wall of the Bowman's capsule are one cell thick and have special structures that allow small molecules to pass through. This filtration under pressure is known as **ultra-filtration** (Figure 2.39). Most of the blood proteins and blood cells do not pass through, as they are too large.

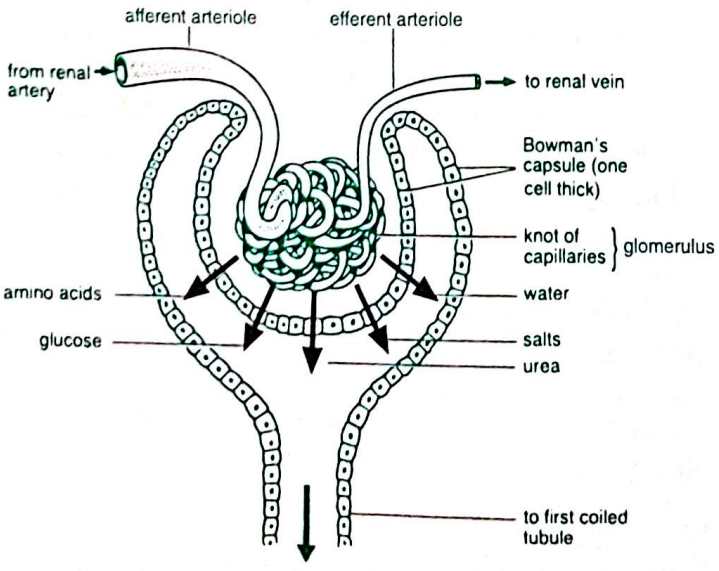


Fig 2.39 Ultra-filtration – diagrammatic.

The filtrate, called **glomerular filtrate**, moves into the first coiled tubule. Here, by osmosis, approximately seventy-five per cent of the water in the filtrate is reabsorbed and all of the glucose is reabsorbed into the blood. The kidneys use energy to ensure this.

The loop of Henlé is the next section of the tubule. Here, a complicated process takes place in which water is reabsorbed according to the body's needs. If the animal has been exercising, thus losing a lot of water through perspiration, more water will be reabsorbed, so the urine will be concentrated and dark in colour. The opposite occurs if the body is water-rich. This mechanism involves anti-diuretic hormone (ADH) and the collecting duct.

The filtrate then moves into the second coiled tubule, where a general 'tidying up' occurs. Any useful materials are reabsorbed and the pH of the blood is regulated. These activities are summarised in Figure 2.40.

The urine then trickles down the collecting duct and into the pelvis. It then moves down the ureters – by gravity and peristalsis – to the urinary bladder, where it is stored. Periodically, the sphincter muscles relax and the urinary bladder is emptied; the urine moving to the outside through the urethra.

The kidney is not only an organ of excretion but also plays a very important part in keeping the water balance (osmo-regulation) and pH of the blood constant.

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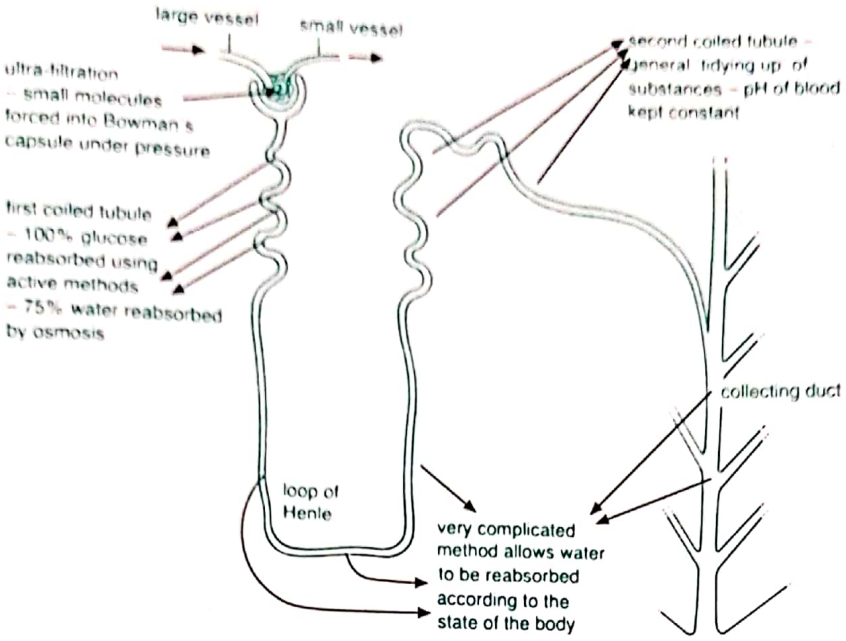


Fig 2.40 Summary of kidney functioning.

Structure of the mammalian skin

The skin of mammals consists of two layers – the outer layer or **epidermis** and the inner layer or **dermis.**

Epidermis

The epidermis is made up of three regions:

- **Cornified or horny layer** – this is the upper, thin region which consists of flat, dead cells which are continually flaking off.
- **Granular layer** – this lies below the cornified layer. It consists of living cells recently produced by the Malpighian layer below. The cells are gradually pushed outwards as new cells accumulate beneath them. A substance called **keratin** is later deposited in them. They lose their nuclei and die, replacing the cornified layer as they become flat.
- **Malpighian layer** – This lies below the granular layer. It is a continuous layer one or two cells thick. The cells are actively dividing and continually producing new epidermis. This region contains the pigment **melanin**, which determines the colour of the skin.

Dermis

This lies below the epidermis. It is a layer of connective tissue containing relatively few cells and many fibres. These fibres make the skin tough and slightly elastic. In the dermis are blood capillaries, nerve endings and lymphatic vessels. Sweat glands, hair follicles and **sebaceous glands** are produced by the epidermis and lie in the dermis. A vertical section through mammalian skin is shown in Figure 2.41.

Functions of the skin

The main functions of the skin are:

- **Protection** – the skin covers the whole body and, as it can withstand mechanical injury to some extent, it protects the underlying tissues. It prevents the entry of pathogens such as bacteria and viruses. It also prevents water loss from the body.
- **Sensing** – the skin contains sensory nerve endings which receive the stimuli of touch, pain, heat and cold so protecting the body against harm.
- **Excreting** – the sweat glands of the skin remove some urea, salts and water from the blood and excrete them as sweat.
- **Thermoregulating** – the body loses or gains heat directly through the skin. Evaporation of sweat from the body causes cooling of the body.

Disorders of the urinary system in humans

Some disorders of the urinary system in humans are kidney stones, urine retention and bed-wetting.

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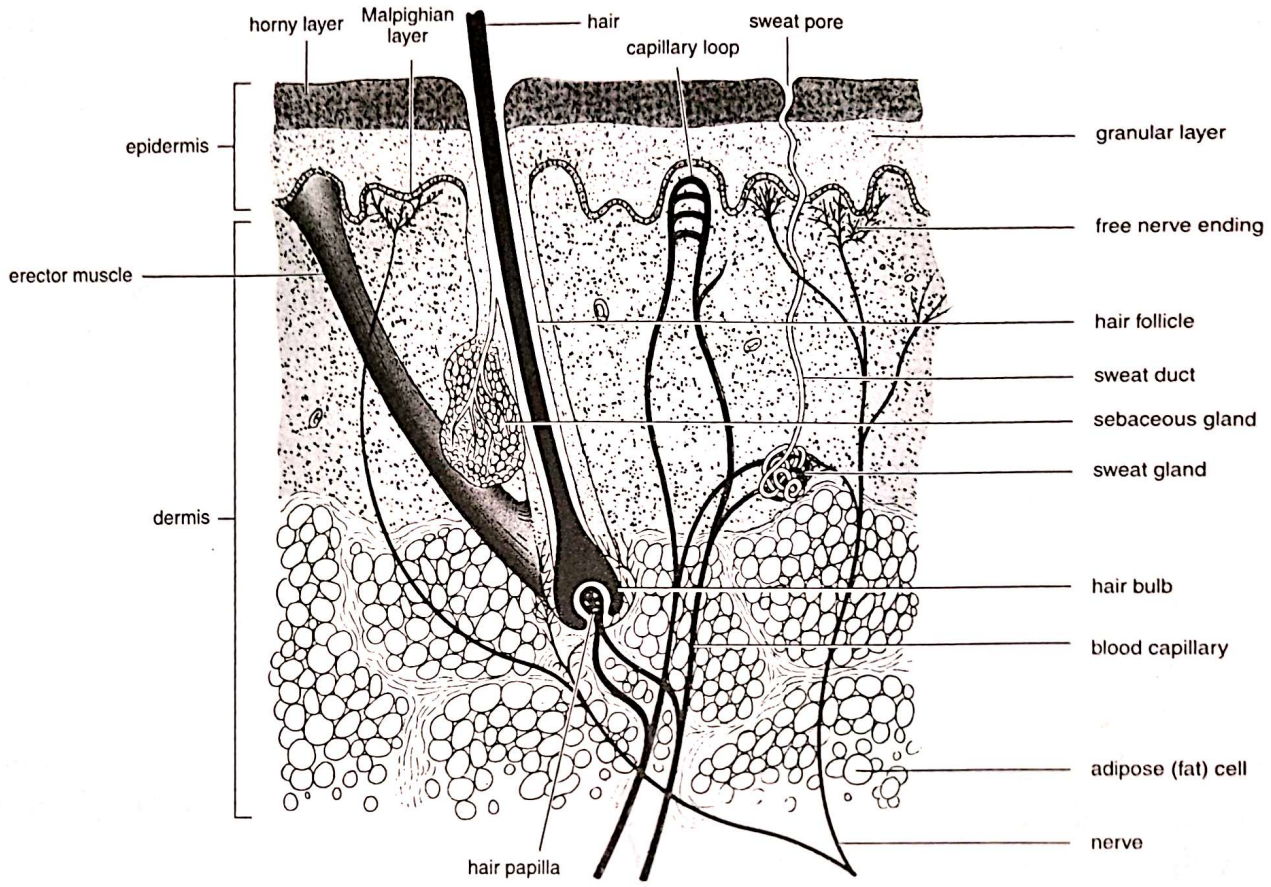


Fig 2.41 Vertical section through mammalian skin.

Kidney stones

These are composed of crystals and proteins. They grow in the medulla of the kidney, then break loose and pass into the renal tubules. Small stones that are anchored in place are not usually noticed but large stones in the pelvis may obstruct the smooth flow of urine. When a stone breaks loose and passes into the ureter it produces a steadily increasing sensation of pain, which often becomes so intense that the patient requires narcotic drugs. Most kidney stones contain crystals of calcium oxalate. They may also be composed of crystals of calcium phosphate, uric acid or cystine. These substances dissolve in normal urine but can form crystals and become kidney stones. Kidney stones can be removed in a special surgical operation or they can be broken up using ultrasound.

Urine retention

Urine retention occurs in both men and women. It is caused by several factors including:

- **Enlarged prostate gland** in males, the prostate gland, which surrounds the upper part of the urethra, may enlarge and cause constriction of the urethra, leading to retention of urine in the urinary bladder because the urine cannot flow through the constriction easily. This may be treated by drugs or by surgical operation.
- **Kidney stones** in the urinary bladder may block the exit, preventing urine from flowing out of the bladder. They can be removed by a surgical operation.
- **Sexually transmitted diseases,** such as gonorrhoea, may leave a stricture (scar) at the exit of the urinary bladder if not treated early. The stricture causes narrowing of the exit, preventing urine from flowing out of the bladder. In severe cases it can be corrected by a surgical operation or in less severe cases by taking antibiotics.

Bed-wetting

This is caused by a number of factors. A common reason, particularly in children, is a disinclination to get out of bed to urinate. Drinking and eating too much in the evening can also cause bed-wetting. Psychological problems can also be a factor. Medical causes of bed-wetting include infection, which can be

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treated with antibiotics and relaxed sphincter muscles surrounding the entrance of the urinary bladder, which can be tightened by exercises or corrected by a surgical operation. A too small urinary bladder also causes bed-wetting, even in adults. A doctor should be consulted if bed-wetting continues for a long time.

Excretion in flowering plants

The waste products of respiration in plants are water and carbon dioxide. The waste product of photosynthesis is oxygen. These are excreted as follows –

- Excess water in the leaf cells diffuses into the air spaces in the leaf. Water molecules in the leaf air spaces diffuse along the concentration gradient through the stomata and into the atmosphere as water vapour. Water is also excreted as water vapour through the lenticels of stems.
- Carbon dioxide produced from respiration is used by flowering plants for photosynthesis during the day. During the night, when there is no photosynthesis, carbon dioxide diffuses through the stomata into the atmosphere.
- During the day, when photosynthesis is actively taking place, oxygen is produced in excess of the plant's needs. The excess oxygen diffuses out of the leaf cells into the leaf air spaces and through the stomata into the atmosphere.

Other excretory products of flowering plants are anthocyanin, fucoxanthin, salts, gums, tannins, resins, lignin and latex. Tannins and resins are stored in some cells. Complex organic substances such as lignin and suberin are then deposited in the walls of these cells. This makes the cell walls impermeable to water and gases such as oxygen. The cells die, keeping the excretory products within them. These dead cells are 'sealed off' and no longer take any part in the functioning of the plant. They do not interfere with the normal functioning of the plant and can be stored without causing any harm. Latex is the milky sap of many plants in which waste products are deposited and which coagulates on exposure to air. Animals have no means of storing their excretory products in this way.

Plants eliminate certain excretory products, for example anthocyanin and fucoxanthin, by transporting them into old leaves, parts of the flower, such as sepals and petals, and ripening fruits. These eventually fall off and so remove the waste.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 How many main excretory organs do mammals have?
- **A** 4
- **B** 3
- **C** 2
- **D** 1

2 Which of these excretory organs remove urea from the body of mammals?
- **A** Kidneys only
- **B** Skin only
- **C** Kidneys and liver
- **D** Kidneys and skin

3 Which of the following structures transports urine from the kidney to the urinary bladder?
- **A** Pelvis
- **B** Urethra
- **C** Ureter
- **D** Pyramid

4 Ultra-filtration is caused by pressure being set up in the glomerulus of the Bowman's capsule because the:
- **A** Afferent arteriole is longer than the efferent arteriole
- **B** Afferent arteriole is wider than the efferent arteriole
- **C** Efferent arteriole is wider than the afferent arteriole
- **D** Efferent arteriole is longer than the afferent arteriole

5 What substances does skin excrete?
- **A** Salts only
- **B** Water only
- **C** Salts, urea and water
- **D** Urea only

6 What do you understand by the term excretion? Distinguish between excretion and egestion.

7 List the excretory products of mammals.

8 Describe, with illustrations, how urine is formed in mammals.

9 State two urinary disorders in mammals and describe how each can be remedied.

10 Briefly explain how the excretory products of flowering plants are eliminated.

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2 Reproductive system and growth in mammals

Learning objectives

After studying this unit, you should be able to:

1 identify the reproductive organs of a mammal and their functions
2 state the advantages and disadvantages of male and female circumcision
3 outline the processes leading to fertilisation, zygote development and birth in humans
4 describe the process of birth in mammals and ways to care for the young ones
5 analyse problems associated with reproduction in humans
6 talk about types of STDs, including HIV/AIDS, how they are transmitted and their effects.
7 identify the phases of growth and development in humans and the associated changes.

Background information

Living things have certain characteristics which make them different from non-living things. These characteristics, called life processes or life activities, are shown by all living things at some period of their lives. One such life activity is **reproduction**.

All living things reproduce, that is, produce offspring to ensure that life continues. **Fertilisation** (the union of the nuclei of male and female gametes or sex cells) is the key to reproduction in sexually-reproducing organisms. A **zygote** is formed as a result of fertilisation. The zygote then develops into a baby.

In humans, certain problems can interfere with the reproductive process. Some, for example ectopic pregnancy, fibroids, infertility, etc. have been identified and, using modern medical techniques can be solved, so that couples with such problems can reproduce. A number of social problems, such as female circumcision, teenage pregnancy and parenthood are also associated with reproduction in humans.

Structure and functions of the mammalian reproductive system

The male reproductive system

The male reproductive system of mammals consists of several parts. The reproductive system of a human male is illustrated in Figure 2.42.

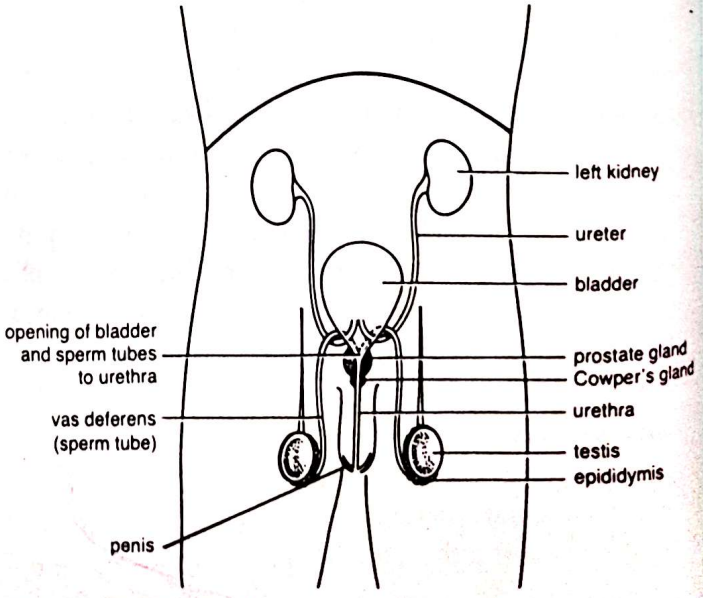


Fig 2.42 Structure of the reproductive system of the human male.

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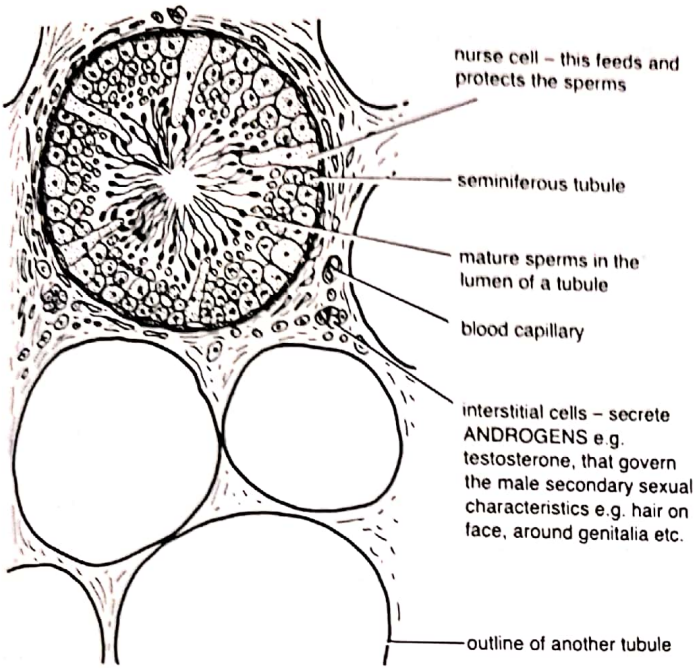


Fig 2.43 A section through part of a mammalian testis.

Testis

Two ovoid (egg-shaped) **testes** lie one on each side of the base of the penis. They hang outside the body in a loose, sack-like, skin, the **scrotum** or scrotal sac, because the temperature inside the body is too high for maximum sperm production. Each testis hangs from a **spermatic cord** which is attached to the body wall at its other end. Blood vessels that serve the testes pass through the spermatic cords. Each testis is composed of numerous highly coiled microscopic structures called **seminiferous tubules** (Figure 2.43). The seminiferous tubules produce sperm, the male gametes, in mature males (Figure 2.44).

The testes also produce a group of male sex hormones, **androgens**. One of these hormones is **testosterone**; it controls the development of male secondary sexual characteristics in mammals.

The seminiferous tubules unite and form another highly-coiled but larger tubule, the **epididymis**. The epididymis stores sperm temporarily and also produces secretions that keep the sperm alive.

Vas deferens

Each epididymis joins a muscular tube, the **vas deferens** or sperm duct. The two vas deferens, one from each testis, open together at the same point into the upper part of the **urethra**, a tube that passes through the penis and opens outside at its tip. The urethra is a passage for both sperm and urine to the outside and is therefore described as urino-genital in function. The vas deferens transports sperm from the epididymis into the urethra for **ejaculation**.

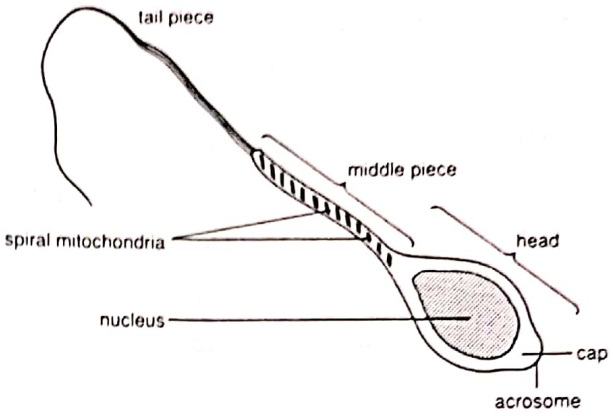


Fig 2.44 Structure of a human sperm.

Penis

The penis in mammals is made up of muscles, many blood vessels and spongy tissue which contains numerous spaces. The tip of the penis of human males, the **glans**, is covered and protected by a loose retractable skin, the **foreskin**.

Seminal vesicles, Cowper's gland and prostate gland

These structures release watery secretions into the urethra during ejaculation. The secretions serve as a watery medium in which the sperm swim. They also contain chemicals which nourish the sperm and enzymes that make them active. The **seminal vesicles** open into the sperm ducts just before they join the urethra. The **prostate gland** surrounds the upper part of the urethra and opens into it there. **Cowper's gland** opens into the urethra just below the opening of the prostate gland. Secretions from these structures mix with sperm to form a creamy-white, jelly-like suspension, called semen or seminal fluid. The secretions can still be called **semen** if sperm are not present.

The female reproductive system

The female reproductive system of mammals consists of several parts, illustrated in Figure 2.45.

Ovary

There are two small, oval-shaped **ovaries** in the lower half of the abdominal cavity, just below each kidney. They are attached to the dorsal wall of the abdominal

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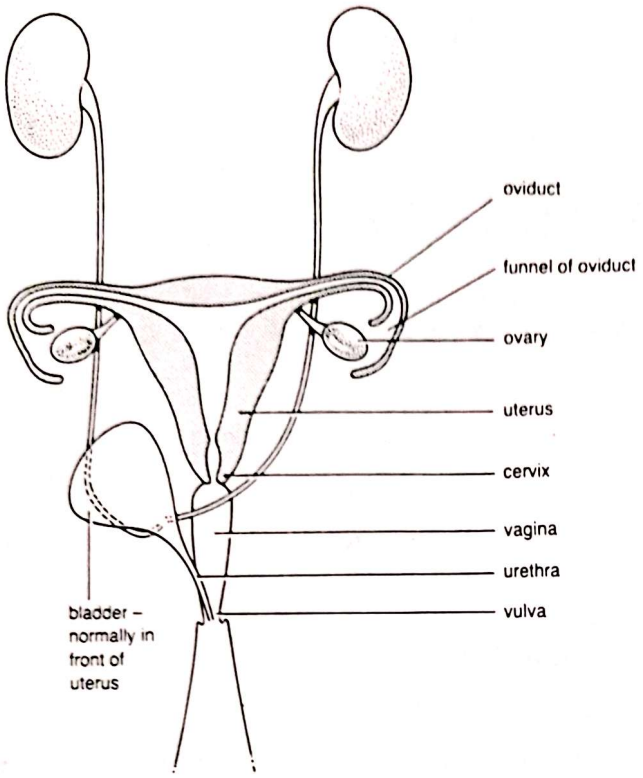


Fig 2.45 Structure of the reproductive system of the human female.

cavity by connective tissue. The ovaries produce egg cells or **ova** (singular **ovum**). They also produce female sex hormones known as **oestrogen** and **progesterone**. Oestrogen controls the development of female secondary sexual characteristics.

Oviduct (Fallopian tube)

This is a muscular tube which leads from each ovary into the uterus. In humans, it is normally about 8–11 cm long. Its mouth forms a funnel shape, which lies very close to the ovary and partly encloses it. Ova are discharged into the oviduct from the ovary. The ovum passes through the oviduct, being moved by ciliary action, from the oviducts' funnel into the uterus.

Uterus (womb)

This is a cavity, with thick muscular walls, which lies in the lower part of the abdominal cavity. Its lower end is surrounded by a ring of muscles, the **cervix**. The cervix opens by a small aperture into the upper part of a muscular tube, the **vagina**. A fertilised ovum develops into a baby in the uterus. The thick walls of the uterus contract and expel the baby during birth.

Vagina (birth canal)

This is a muscular tube which leads from the uterus and opens to the outside. The vagina and urethra open separately to the outside at the **vulva**. Two pairs of lip-like flaps, the **labia**, enclose the vulva and protect the entrance of the vagina. The vagina receives sperm during sexual intercourse. It is also the canal through which the baby passes to the outside during birth. Just above the entrance of the urethra is a small, sensitive muscular protrusion, the **clitoris** which becomes erect during sexual excitement.

ACTIVITY 1 Studying the male and female reproductive systems of mammals

1 Your teacher will dissect male and female guinea pigs or rabbits and display the male and female reproductive systems. You will also be provided with charts showing the male and female reproductive systems of humans.

2 Identify and draw the parts in the dissections using the charts and Figures 2.42 and 2.45 as guides. Label your drawings.

3 State the function of each part you have labelled.

Male and female circumcision

Circumcision literally means 'cutting round'. In human males, the foreskin of the penis is removed in a simple operation. In human females, circumcision involves removal of the clitoris and sometimes part of the vaginal lips. Some tribes, communities and ethnic groups practice circumcision of either males or females or both. Circumcision has advantages, disadvantages and cultural values but is not necessary; a person can live a normal life without being circumcised.

Advantages of circumcision

In boys

- The foreskin covers a space where germs can breed and cause infection, leading to damage of the penis.
- A yellowish cream-like substance can accumulate below the foreskin. It is believed that the substance can cause cancer of the penis if it is not regularly removed by cleaning the tip of the penis.

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- The foreskin may become abnormally red, swollen and tight, causing pain when a young boy passes urine. It is necessary to remove the foreskin by circumcision in this case.

In girls

None of the reasons for female circumcision have any scientific basis but in some cultures it is believed that –

- removing the clitoris allows direct dilation of the vagina during birth, thus making delivery easier.
- removal of the clitoris allows free outflow of urine. As the entrance of the urethra is just below the clitoris, it may extend over it and obstruct free outflow.
- penetration of the vagina by the penis during sexual intercourse is easier if the clitoris is not there.

Disadvantages of circumcision

In both boys and girls –

- Circumcision may result in excessive bleeding from the wound.
- The wound may become infected by germs if it is not properly cared for.
- If a new sterilised blade is not used for performing the circumcision, the instrument may carry germs and infection may lead to the death of some children.
- Using the same blade on more than one child without sterilisation in between may lead to transmission of the AIDS virus.
- Removal of the sensitive clitoris makes a circumcised woman sexually unresponsive.
- Removal of part of the vaginal lips, in addition to the clitoris, often makes childbirth difficult.

Cultural values of circumcision

In some tribes circumcision is customary, as it is believed to confer manhood or womanhood on the individual in the eyes of their society. Some tribes insist that a royal male must be circumcised to qualify him to be chief of his people. These tribes believe that circumcision declares a man or woman holy. On the other hand, male circumcision of royalty is forbidden in some ethnic groups and tribes. They hold the view that royal blood should not be shed in any manner. A circumcised male from the royal family is therefore held to be unholy and is disqualified from becoming the chief. Holiness, in terms of being circumcised or not, is a matter of religious and traditional beliefs, for example, all male Jews are circumcised.

In some tribes it is believed that sexual unresponsiveness in women, as a result of circumcision, prevents women having extra-marital sex. It is also believed it leads to the spacing-out of children since the woman can neither frequently nor easily become sexually aroused. In some tribes, a woman must be circumcised to qualify to become the queen mother. Such a woman either has the tip of her clitoris cut off or the whole clitoris removed.

In extreme cases, the whole clitoris and the labia are cut off. The vulva is then sewn up, leaving only a small hole for passing urine. Such women experience very painful sexual intercourse and difficult childbirth. Some circumcised women feel ashamed of not possessing a clitoris and this kills their sexual desire. Such women may refuse to get married because they may not want a man to know about their condition.

Human rights activists and health workers see female circumcision as socially cruel and a punishment for women. They view female circumcision as destruction of the womanhood of the affected person. These people and others strongly oppose female circumcision and advise that it should be totally abolished.

ACTIVITY 2 Debate on female circumcision

1 Hold a class debate on the subject 'Female circumcision should be abolished'.

2 Divide the class into two groups to put forward arguments for and against.

Fertilisation, development of the zygote and birth in mammals

Fertilisation

In all mammals, and most animals that live on land, fertilisation is internal. Fertilisation is preceded by sexual intercourse, also known as copulation or **coitus**. When the male becomes sexually excited, blood rushes into the spaces in the spongy tissue of his penis. This makes the penis turgid (stiff and hard) and larger, a

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condition known as an erection. In this state, the penis can penetrate the vagina.

Movements of the penis in the vagina by the male cause a pleasant sensation that leads to ejaculation and orgasm. The woman also experiences pleasurable sensations that lead to contractions of the vagina and orgasm.

Ejaculation is the release of semen from the penis.

A man produces about 3–7cm^3 of semen, containing about 50 to 500 million sperm, in one ejaculation. As soon as the sperm are deposited in the vagina they swim very quickly in the watery medium provided by the semen and secretions from the lining of the vagina. They pass through the small opening of the cervix into the uterus and then into the oviducts. If there is an ovum in the oviducts, many sperm will bump into it and one may penetrate it. This sperm then sheds its tail and its nucleus fuses with that of the ovum. This is **fertilisation** (Figure 2.46).

The fertilised ovum is called a **zygote**. Fertilisation normally occurs in the upper part of the oviduct. A sperm can fertilise an ovum for two to three days after its release, though the ovum can live for about eight days.

Development of the zygote

After fertilisation, the zygote divides regularly and repeatedly. These cleavages produce 2, 4, 8, 16, 32, 64, 128 cells and so on up to a point where the cell divisions become irregular and a small ball of cells is formed. This ball moves through the oviduct into the uterus, which is specially prepared to receive the developing zygote. Its walls become very thick and have a good supply of blood and nutrients. Further cell divisions and cell organisations form the earliest stage of an embryo, the **blastocyst**. This sinks or **implants** into the lining (**endometrium**) of the uterus and begins to develop into a baby. Implantation often occurs on the posterior surface of the uterus. At this stage the woman is said to be **pregnant** or to have **conceived**.

Implantation is the embedding of the blastocyst into the endometrium (lining) of the uterus.

If fertilisation or implantation fails, the thickened inner lining of the uterus breaks down. The break-down substances from the uterine wall, together with the unfertilised ovum, mucus and a quantity of blood, pass out through the vagina. This is known as **menstruation**. This occurs in a regular cycle, the **menstrual cycle**. In women, the cycle varies from 28 to 35 days. The release of the ovum, known as ovulation, occurs at the middle of the menstrual cycle (Figure 2.47).

A similar cycle, known as the **oestrous cycle**, occurs in other mammals but there is no outflow of blood. When an oestrus cycle occurs, the female is ready for mating and shows certain signs which serve to stimulate the male. She is said to be 'on heat'.

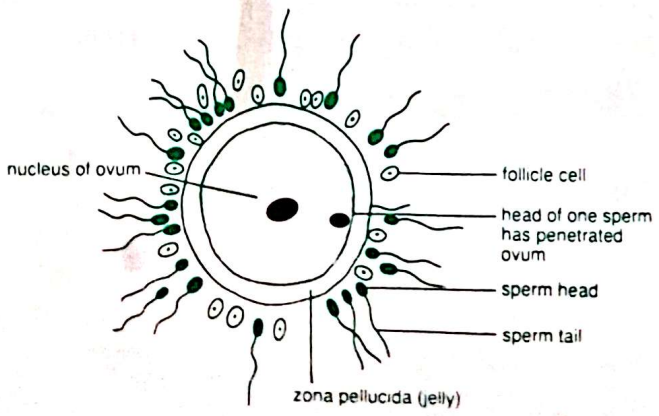


Fig 2.46 Fertilisation of an ovum.

Development of the ova

The ova are formed from groups of cells called **Graafian follicles**. After releasing an ovum a Graafian follicle develops into a structure called the **corpus luteum** or yellow body (Figure 2.48).

The corpus luteum produces **progesterone**, a hormone that causes the thickening of the uterine wall to prepare it to receive the developing zygote. When the embryo is implanted, it derives nutrients from the uterine wall until a structure called the **placenta** is formed on the uterine wall.

Each ovary contains many Graafian follicles at various stages of development. This can be seen in Figure 2.48. There is a definite series of stages in the development

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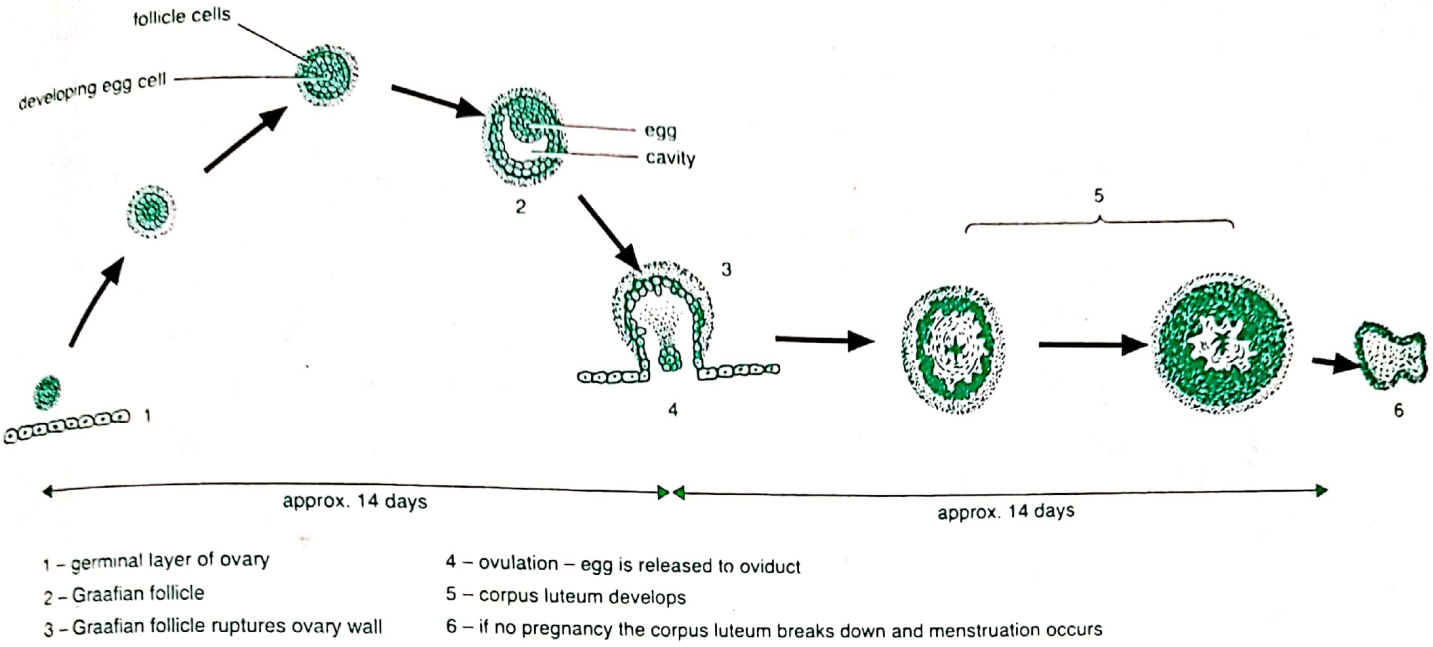


Fig 2.47 Stages in the menstrual cycle in human females.

of the Graafian follicles, ovulation and formation of the corpus luteum. These are summarised in Figure 2.47. Ova are produced from puberty until menopause. Each ovary contains about 17 000 potential ova (egg cells) at birth. Out of these, only about 500 will become mature ova in a woman's lifetime and only a few will be fertilised. A woman's reproductive lifetime is about thirty years.

The placenta

The placenta (Figure 2.49) is made up of tissues from both the mother and the embryo. The embryo is connected to the placenta by a cord-like structure, the **umbilical cord**. This cord contains blood vessels which carry materials from the mother to the embryo and from the embryo to the mother through the placenta. The placenta has a rich supply of blood from numerous blood vessels. The blood supplies of the mother and

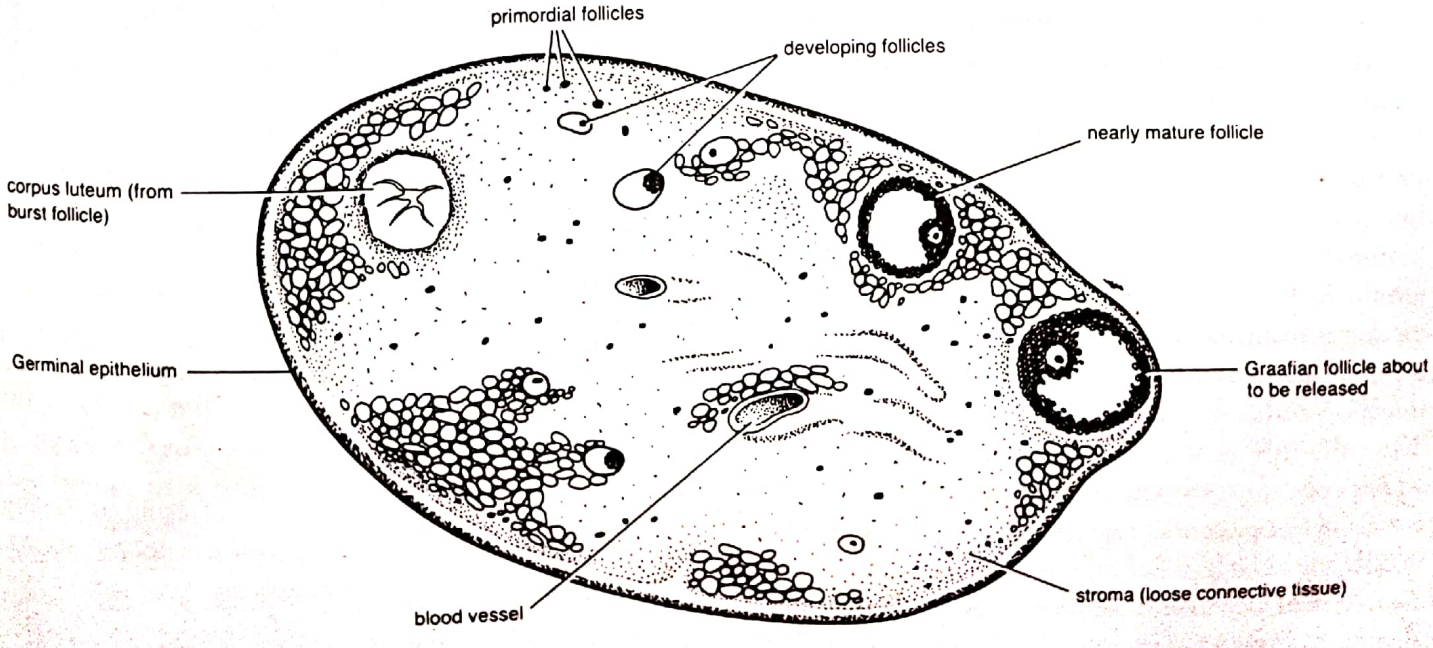


Fig 2.48 A section through a mammalian ovary showing the Graafian follicle at various stages of development.

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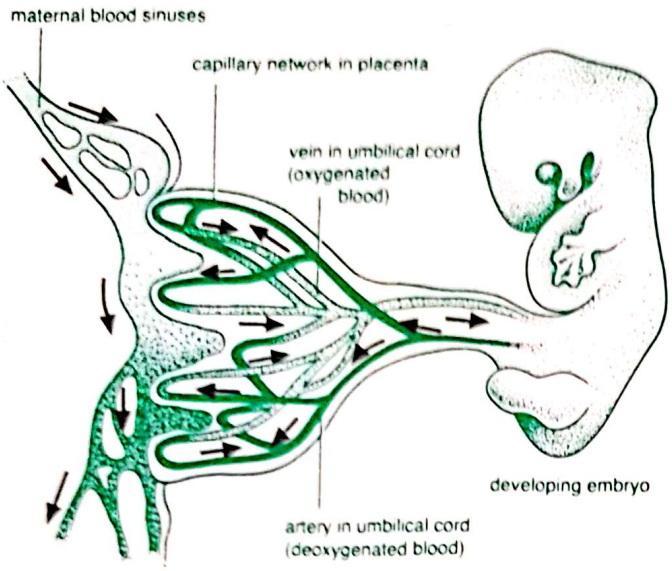


Fig 2.49 Structure of the placenta.

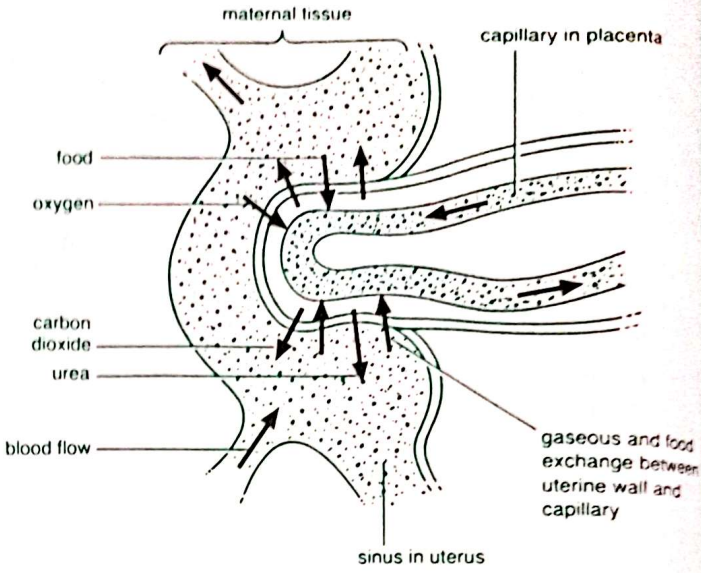


Fig 2.50 Diffusion of substances through the placenta.

embryo are in close contact but *do not mix*. The membranes that separate the mother's blood from that of the embryo are very thin. This facilitates the passage of materials in both directions. The embryo absorbs nutrients and oxygen from the mother by diffusion. Waste metabolic substances such as urea and carbon dioxide (CO_2) pass from the embryo into the mother's blood for excretion by the mother (Figure 2.50).

Apart from exchanging materials between the mother and embryo, the placenta also takes over the secretion of the hormones of the corpus luteum. These hormones prevent ovulation and menstruation and sustain the pregnancy.

Four structures, the **embryonic membranes**, are formed around the embryo. The **chorion** is the outermost membrane and encloses the other membranes. It protects the embryo and the membranes beneath. Part of the chorion also takes part in the formation of the placenta. The **amnion** forms the sac-like cavity, the **amniotic cavity**, which contains a thick liquid called **amniotic fluid**. The embryo develops in this watery medium, insulated and protected against temperature changes. The amniotic fluid protects the embryo against infection and dehydration and acts as a 'shock absorber'. The **allantois** is a vestigial (undeveloped)membrane which does not surround the embryo but provides blood vessels in the placenta. The **yolk sac** is another vestigial membrane which supplies food to the embryo until the placenta is formed. These and other structures are illustrated in Figure 2.51.

About three months after a pregnancy begins, the embryo has developed into the youngest stage of a human. At this stage, it is called a **foetus**. It has human features, from head to toes and fingers. The foetus begins moving its arms and legs by the end of the fourth month of pregnancy and the mother can feel this. About nine months after fertilisation, the foetus is fully developed into a **baby** and is ready to be born.

The period between fertilisation and birth is known as the **gestation period**. This period varies between different mammals (Table 2.6).

Table 2.6 Gestation periods in mammals compared

Mammal	Gestation period
mouse	3 weeks
rabbit	1 month
dog	2 months
goat	5 months
human	9 months
cow	10 months
whale	12 months
elephant	22 months

Formation of twins

The ovaries normally alternate in releasing an ovum once a month but sometimes both ovaries release an ovum at the same time. If both ova are fertilised, twins, called **fraternal** (or non-identical) **twins** are produced. These twins may be of the same sex or different sexes.

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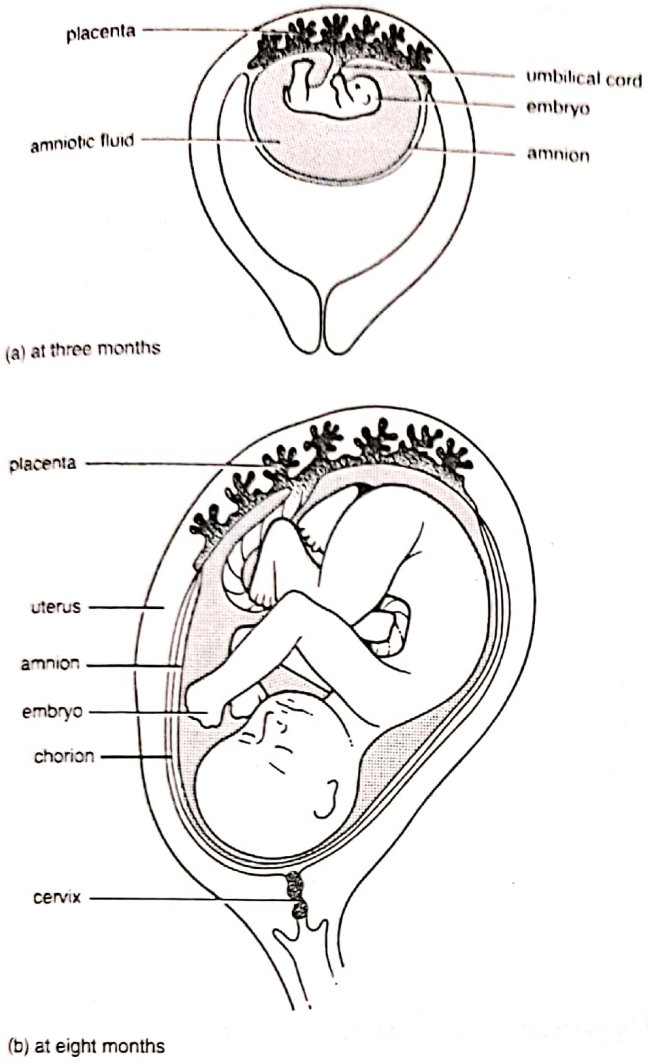


Fig 2.51 Stages in the development of the human foetus.

are not genetically identical and will not be physically alike.

Occasionally, a fertilised ovum splits into two separate cells during the first cleavage. If the two cells both develop into embryos, **identical twins** are produced. These twins are genetically identical, that is, they have the same genes, since they come from the same ovum. Identical twins are always the same sex and have identical features, for example they have the same finger and thumb prints.

In some cases, three or more ova are released by the ovaries or a single zygote may split a number of times into three or more separate cells. This results in **multiple births** of triplets (three babies), quadruplets (four babies), quintuplets (five babies) or more. These babies are usually born prematurely, because the womb cannot cope; often, some babies do not survive. Women who use fertility drugs to become pregnant often have multiple births.

Multiple births are unusual in humans but common in other mammals such as pigs, dogs, mice and rabbits. The offspring of these mammals are collectively called a **litter**.

Conjoined twins

In very rare cases, the zygote divides into two cells which do not completely separate and **conjoined twins** are then produced. These twins are joined together at some part and may even share vital organs like the liver and kidneys. The first recorded conjoined twins came from Siam (now Thailand), hence conjoined twins are sometimes called **Siamese twins**. Conjoined twins have the same sex and are identical. It is possible to separate conjoined twins but often one or both of the twins dies as a result. The first instance of conjoined triplets was recently recorded.

Birth in mammals

In humans, after about forty weeks of pregnancy, the foetus is ready to be born. By this time, it has moved so that its head lies towards the cervix. Birth has three stages:

1 Dilation – the cervix of the uterus stretches.
2 Expulsion – baby emerges from the birth canal.
3 Placental – the placenta is expelled as the afterbirth.

Birth begins with **labour**. This involves powerful contractions of the highly-thickened walls of the uterus. The abdominal walls also contract. The embryonic membranes are broken as a result of these contractions and the amniotic fluid flows out through the vagina, lubricating it. This is known as the 'waters breaking'. The cervix dilates (becomes wider). The vagina, which has now become highly thickened, contracts.

The foetus gradually emerges from the vagina and eventually comes out, usually head-first (Figure 2.52). Occasionally, the foetus emerges feet-first – this is known as **breech birth**.

In humans, the umbilical cord is tied in two places with thread and then cut in between the tie. This prevents bleeding from both mother and baby. Further powerful contractions of the walls of the uterus and abdomen expel the placenta, together with the

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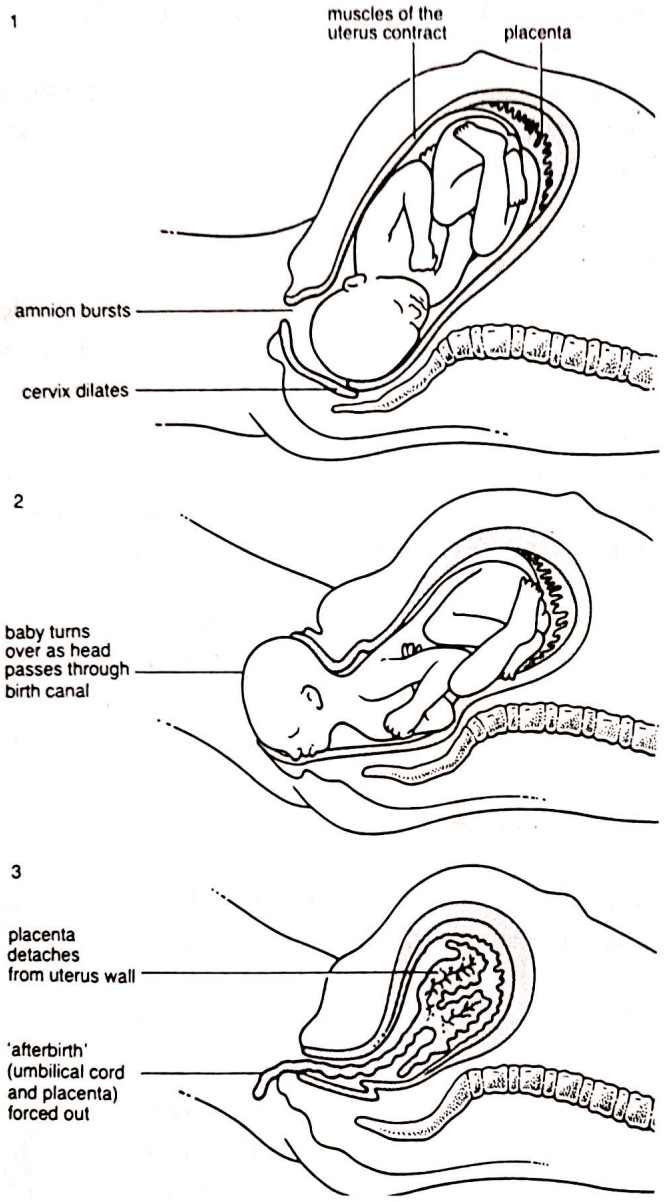


Fig 2.52 Stages of birth.

remaining portion of the umbilical cord and embryonic membranes. This is referred to as the **afterbirth**. It is important that the placenta is expelled quickly after birth. If it remains in the mother for too long, it becomes rotten and may poison her. This results in the death of some women during childbirth.

Reproductive hormones

The processes involved in sexual reproduction in mammals are controlled by specific hormones (Table 2.7).

Table 2.7 Summary of reproductive hormones

Hormone	Action
oestrogens	produce female secondary sexual characteristics; involved in ovulation and menstruation
progesterone	prepares the uterus for pregnancy; inhibits contraction of the uterine wall, ovulation, menstruation and prevents breakdown of the prepared uterine wall during pregnancy
oxytocin	causes uterine contractions during birth
prolactin	stimulates secretion of breast milk after the baby is born
androgens, for example testosterone	produce male secondary sexual characteristics

ACTIVITY 3 Studying the stages of development of the human foetus and birth

1 Your teacher will provide charts showing the stages of development of the human foetus and birth.

2 Study the charts carefully and use Figures 2.51 and 2.52 as guides to draw and label the charts.

Parental care in humans

Parental care in humans has three stages: pre-natal (or ante-natal) care, post-natal care and child care. Human parental care follows the basic pattern common to all mammals except that it is planned and consciously carried out. Human children depend on their parents for a longer time than those of other mammals. Human parents must provide food, shelter, warmth, protection, education and the moral upbringing which will enable their children to fit well into society.

Pre-natal care

This involves supervision of the pregnant woman by a midwife or doctor. First and foremost, a pregnant woman must stay healthy throughout the pregnancy, by eating the right kind of food and taking regular exercise, as prescribed by the midwife or doctor. She must eat foods rich in iron such as meat, eggs, beans, chicken, fish and leafy green vegetables. She should also take iron tablets (325mg) twice a day and 1mg of folic

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acid once a day, until the baby is born. Eating fruits such as mangoes, pawpaw and oranges helps the body to use iron efficiently.

The midwife or doctor should educate and encourage the pregnant woman to attend a pre-natal clinic early in the pregnancy and once every four weeks till the 28th week, fortnightly till the 36th week and weekly until the birth. The husband should also be educated on pregnancy and advised to be involved in planning and preparations for the arrival of the new baby.

The aims of pre-natal care are to –

- maintain and encourage the physical, mental and spiritual well-being of the mother throughout the pregnancy
- detect early and treat any pre-existing abnormalities, such as anaemia and infection
- ensure that the mother passes safely through the pregnancy and labour and delivers a live healthy baby with minimal injury to both mother and baby
- detect early and treat promptly any medical abnormality that arises during the pregnancy, as this may harm both the mother and baby
- prepare the mother for the post-natal care of the baby
- assist the mother to return to a good state of health after delivery and rehabilitate her (help her to fit) into the family with her new baby.

Pre-natal care is important because it helps to –

- reduce the number of maternal and foetal deaths
- diagnose abnormalities and treat them early
- reduce complications during labour, for example rupture of the uterus, excessive bleeding after birth and delayed second stage (expulsion)
- improve the general health of both mother and child, thus improving the health of the nation.

Post-natal care

After birth, a large wound is left on the uterine wall where the placenta was attached. This wound takes some time to heal and care must be taken to prevent infection. This is done by regular bathing, with soap, antiseptics and disinfectants. The woman must also undertake regular exercise, as prescribed by the midwife or doctor, so that her muscles regain their strength after being stretched during birth. The mother should go back to the clinic two weeks after delivery, and again after six weeks for post-natal examination, to make sure that all the organs that participated in the birth process have regained their normal state and that her health and that of the baby are normal.

Child care

The new-born baby should be bathed regularly. The mother should wrap the baby up properly to keep it warm, especially in cold weather. This is necessary because a baby's temperature-regulating mechanisms take some time to become established. The baby should be properly fed.

Breast-feeding

Soon after birth, the baby is put to the breast and begins to suck at its mother's nipples. This stimulates the breasts to release milk. The first fluid released from the breasts is **colostrum**, a yellowish liquid which contains proteins (immunoglobulins) that prevent infections. Mothers should be educated and encouraged to feed their new babies with colostrum, since the baby's immune system also takes some time to become established. True milk starts flowing from the breasts two or three days after birth.

Breast milk contains all the essential food substances required by babies for body-building and to meet their energy needs in the correct proportions and quantities. Breast-feeding is psychologically and emotionally beneficial to both the mother and child because it promotes the formation of a strong bond. Breast milk is ready-made, fresh and hygienically clean, unlike modified cows' milk, which can be contaminated by germs during its treatment. Breast-feeding is gradually supplemented and eventually replaced by solid food. This changeover in feeding regime is known as **weaning**.

Bottle-feeding

Some parents feed their child with artificial milk from feeding bottles. The artificial milk is cows' milk, treated and mixed with various substances to make it more like human milk. Great care must be taken to keep the feeding bottles and their teats clean.

Immunisation

Children must be immunised against certain diseases to protect the population. These diseases are popularly known as the *six killer diseases* (see Table 2.8).

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Table 2.8 Immunisation of children

Disease	Vaccine	Method	Time after birth
diphtheria	anti-diptheria	injection	6 weeks, 10 weeks and 14 weeks
measles	anti-measles	injection	9 months with anti-yellow fever, 6 months at times of epidemics
poliomyelitis	anti-poliomyelitis	oral	at birth, 6 weeks, 10 weeks and 14 weeks
tetanus	anti-tetanus	injection	6 weeks, 10 weeks and 14 weeks
tuberculosis (TB)	BCG (anti-tuberculosis)	injection	at birth only
whooping cough (pertussis)	anti-whooping cough	injection	6 weeks, 10 weeks and 14 weeks

Disadvantages of teenage pregnancy and parenthood

Teenagers are boys and girls between the ages of 13 and 19. Teenage pregnancy can be caused by a teenage boy or an adult man. Teenage parenthood may involve a teenage girl and a teenage boy, a teenage girl and an adult man or a teenage boy and an adult woman.

Any teenage pregnancy poses a number of problems, including:

- A break in education – a pregnant teenage girl has to leave school. A teenage boy responsible for a pregnancy may also have to leave school and find work to support the girl if their families cannot help. Similarly, the professional training of one or both partners may be disrupted.
- Improper feeding – the pregnant girl may have a poor diet due, to lack of financial support, since the boy and girl are not usually gainfully employed. This leads to malnutrition, which adversely affects the unborn child.
- Undue reliance on parents – financial support in terms of feeding, accommodation, healthcare, clothing, education of the child, etc. has to be provided by the parents of the teenage couple.
- Embarrassment for teenagers and their families.
- Inability to take proper care of the baby.
- Criminal abortions – the girl and boy may not want their parents and other people to know of the pregnancy. Because of the shame involved, some parents, especially those of the girl, may turn to criminal abortion, to avoid public knowledge. The family of the girl may not want their daughter to marry into the boy's family, so may resort to criminal abortion. Criminal abortion may lead to the death of the girl or cause post-abortion problems, such as fibroids and infertility.
- Forced marriage – this may be short-lived or may be a lasting but unhappy marriage. In most situations leading to teenage pregnancy, the couple do not love each other.
- Fatherless children – the father is often unwilling to accept responsibility for the pregnancy and the girl remains unmarried.
- Uncertainty, insecurity and discomfort on the part of the girl – if she does not marry the father of her child she is likely to remain unmarried, since many men do not want to marry a woman who already has a child.
- Death of teenage mothers during childbirth – some girls are not developed enough to deliver a baby.
- Abandoned babies – some teenage mothers, out of despair, leave their baby somewhere, for example under a tree, at the wayside or near a church or houses, in the hope that someone will find it and care for it.

Some problems associated with reproduction in humans

A number of problems are associated with reproduction in humans, some more serious than others.

Miscarriage

Normally a baby is born after 40 weeks of pregnancy. However, if the pregnancy ends after only 28 weeks it is described as a premature delivery or **miscarriage**. A miscarriage occurs when the foetus is expelled from the uterus unintentionally. It is not planned. Miscarriages are caused either by maternal or foetal factors. Maternal factors include:

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- hard physical activity by the mother early in pregnancy
- injury to the mother's abdomen
- emotional stress or shock
- diseases and infections, such as German measles, syphilis and malaria
- an abnormal uterus
- a hormonal imbalance.

Foetal factors include:

- abnormal implantation
- poor attachment of the placenta
- poor development of the foetus
- abnormality of the foetus.

Abortion

An induced **abortion** is carried out on purpose in order to end the pregnancy. Induced abortions can be carried out in a hospital by a recognised surgical team in order to save the life of the mother or in order to remove an unwanted pregnancy. Many people regard the latter kind of abortion as immoral.

Abortions may lead to problems including:

- a high possibility of injuring blood vessels, especially an artery
- a high possibility of damaging reproductive organs if sharp objects are

used

- excessive bleeding and, sometimes, the death of the mother
- damage to the cervix, which may lead to future spontaneous abortion
- infections, bleeding and blood poisoning
- hormonal imbalances, preventing future pregnancy
- general ill health
- pelvic inflammation, which might cause future miscarriages
- psychological suffering.

Ectopic pregnancy

Ectopic means 'out of place'. This is a condition in which the fertilised ovum embeds outside the uterine cavity. There are several causes of ectopic pregnancy, including:

- Diseases affecting the oviducts or abnormal oviducts – fertilisation usually takes place in the upper portion of the oviduct. The fertilised ovum is then propelled towards the uterus by the movement of cilia and peristaltic movements of the oviduct. The zygote develops during its journey and if there is any delay or anything preventing it from moving into the uterine cavity, it will implant in the oviduct when it reaches the blastocyst stage. This results in **tubal pregnancy**.
- Abnormal ovum – abnormally rapid growth of the fertilised ovum may result in premature embedding in the oviduct.
- Abdominal pregnancy – a rare condition that occurs when the zygote is expelled into the abdominal cavity through the ovarian end of the oviduct. A live foetus may be formed and attached to the abdominal wall by an abnormal placenta. The foetus may die from lack of nourishment but may develop into a baby that can be delivered by a doctor in a special surgical operation.
- Ovarian pregnancy – a condition in which a sperm fertilises an ovum when it is still in the Graafian follicle. The effect is that the ovary may rupture, resulting in bleeding into the body of the ovary. The fertilised ovum may die and form a mole inside the ovary. This may or may not harm the woman.

Effects of ectopic pregnancy

All forms of ectopic pregnancy are dangerous both to mother and baby. A fertilised ovum may die in the oviduct if it does not get enough nourishment. It may then become detached from the wall of the tube and be expelled into the abdominal cavity through the ovarian end of the oviduct. This is known as **tubal abortion**. Infection of the dead foetus produce toxins and the mother may die if an operation is not performed promptly.

As the foetus grows and becomes larger in the oviduct, its walls become distended and weak. This causes tension in the oviduct, which may burst, bleed and release the foetus into the abdominal cavity. This tubal rupture results in sudden abdominal pains associated with bleeding from the vagina.

Infertility

When couples fail to produce a child after two years of regular sexual intercourse, either the woman or man, may be **infertile**.

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The traditional, unscientific, Ghanaian view of infertility is that it is due to a curse or witchcraft.

Treatment of infertility in both men and women is medical in mild cases and surgical in severe cases. If the cause of infertility is due to sexually transmitted diseases (STDs), men can be more easily treated than women, since STDs are more easily detected in men. If detection is late, treatment will not prevent infertility because the disease will already have caused damage. Hormonal therapy can increase the production of sperm and semen. If occupation is the cause then a transfer or change in occupation is advised.

Causes of infertility in men include:

- **Absence of sperm** – caused by infections, for example mumps (which affects males in childhood), tuberculosis and partially or incompletely treated sexually transmitted diseases, such as gonorrhoea and syphilis, which damage the testes.
- **Low sperm count** – at one ejaculation a man produces 3 to 7cm^3 of semen containing 50 to 500 million sperm, of which fifteen per cent must be powerful. If the number of sperm produced falls below a certain minimum figure, the man is unlikely to impregnate a woman. Low sperm count may be caused by underdevelopment or improper development of the testes, congenital diseases, occupations in which a man's scrotum is exposed to excessive heat, working with certain chemicals or X-ray radiation which may damage the reproductive organs, old age, excessive drinking of alcohol and smoking.
- **Defective** or abnormal sperm.
- **Obstruction** (blockage) or absence of the vas deferens. This may be due to disease or infection.
- **Premature ejaculation.**
- **Impotence** – the man is incapable of having sexual intercourse.

Causes of infertility in women include:

- **Failure** to produce ova or failure to release them.
- **Obstruction** (blockage) of the oviducts as a result of infection.
- **Adhesion** (sticking together) around the oviducts which prevents the ovum from passing through the lumen of the tubes.
- **Endometrial hostility**, that is, the lining of the uterus does not allow the fertilised ovum to implant.
- **Faulty timing** of coitus.
- **Painful coitus.**
- **Age** of the woman; under 18 years and after the age of 35 years the chances of conception are lower.
- **Diseases** such as tuberculosis, chronic nephritis and sexually transmitted diseases such as syphilis and gonorrhoea, leading to infection of the reproductive organs.
- **Poor diet** deficient in vitamins and proteins.
- Excessive **hard work** which prevents ovulation.
- Change of **environment.**
- Exposure to **X-rays.**
- **Incomplete** or criminal **abortion** – the use of native medicines to cause abortion can lead to infection which in turn destroys some of the reproductive organs.
- **Fibroids** (see below).
- Constantly working near **fire.**
- High levels of the hormone **prolactin** in the blood, which prevents ovulation. This may be stress-related or caused by certain drugs. Such women have milk in their breasts at the wrong time. Continued breast-feeding after birth maintains a high level of prolactin in the blood.
- Being **overweight**, **underweight** or taking excessive exercise reduce the chances of ovulation.

If the cause of infertility can be identified, it may be treated.

Fibroids

A fibroid is an abnormal growth or tumour in part of the uterine muscles or muscles of the cervix. It grows from the inner wall of the uterus or cervix, often where there is a scar as a result of abortion or miscarriage. It may grow to any size as a smooth, rounded swelling which is continuous with the uterine wall or wall of the cervix. This swelling may grow into the uterine cavity or into the uterine wall. Fibroids do not often show any symptoms but can be felt through the vagina on pelvic examination by the doctor. Fibroids are suspected when:

- there is a history of infertility or reduced fertility
- there is a history of abortion or miscarriage
- the woman is over 30 years of age and complains about abdominal discomfort, pain and a heavy feeling in the lower abdomen
- the uterus is an abnormal shape

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- there is progressive, irregular menstrual discharge
- deep pain is experienced during sexual intercourse.

Fibroids have serious adverse effects on fertility and pregnancy. Fibroids located in the uterine cavity may prevent fertilisation, by blocking the entrance of the oviducts. They may also prevent implantation, causing infertility in some women. Fibroids may grow and occupy much of the space in the uterus, leaving just a small space for the foetus. This may lead to abortion or miscarriage.

A special surgical operation, *myomectomy* can be performed to remove fibroids. This may lead to the woman regaining her fertility.

Impotence

Erection is a purely vascular affair. It is caused by parasympathetic (involuntary) nerve impulses passed from the spinal cord to the penis. This leads to dilation of the arteries of the penis and accumulation of arterial blood under high pressure in the erectile tissues, leading to erection of the penis. Impotence means permanent failure of the penis to erect.

Causes of impotence include:

- damage to the parasympathetic nerves to the penis
- damage to the sensory nerves to the penis and surrounding areas, such as the anal epithelium and scrotum, leading to loss of sensory sensation which is important for initiation of the sexual act
- damage to the part of the spinal cord where impulses involved in the sexual act are linked.

Sexually transmitted diseases (STDs)

Sexually transmitted diseases (STDs) or sexually transmitted infections (STIs), are a group of diseases spread by sexual contact. The two main ones are **gonorrhoea** and **syphilis**, both of which are caused by bacteria (see Year 1, Section 5, Unit 4). They can be successfully treated by antibiotics, particularly in the early stages. In recent years, another very important STD has become known: **AIDS**. This is caused by the human immunodeficiency virus (HIV). Viruses do not respond to antibiotics so, unlike the two diseases mentioned above, AIDS cannot be effectively treated. Indeed, there is as yet no effective cure (see Year 1, Section 5, Unit 4). This is becoming a very serious problem and emphasises the point that casual sexual relationships are to be avoided. Table 2.9 gives details of common STDs.

ACTIVITY 4 The effects of STDs

Work in groups to discuss the effects of STDs on health and reproduction.

Ovarian cyst

An ovarian cyst is any collection of fluid, surrounded by a very thin wall, within an ovary. Most ovarian cysts are harmless and can affect women of all ages. They occur most often, however, during a woman's childbearing years. Some ovarian cysts cause problems, such as bleeding and pain. Surgery may be required to remove these cysts.

Stages of growth and development in humans

Growth and development begin at conception. They happen through cell division and involve a series of changes and reorganisations in the body from the foetal stage to old age. They also involve development of secondary sexual characteristics, changes in behaviour, attitudes and functions of the body.

For males and females, growing up and sexual maturity bring physical and behavioural changes to which the body has to adapt. Problems such as sexually transmitted diseases and early parenthood are associated with these changes.

Growth is a steady increase in size which takes place as a human develops. It starts with a fertilised egg cell – a zygote – and continues as this cell divides into 2, 4, 8, 16 cells and so on. In humans, the stages of growth and development include:

- pre-natal
- infancy
- childhood (pre-school, middle childhood)
- adolescence
- adulthood
- old age.

Pre-natal

This is the period from conception to birth – about forty weeks for a full-term pregnancy. The body systems are already well developed by the end of the

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Table 2.9 Sexually transmitted diseases

Disease	Causative agent	Mode of transmission	Symptoms	Prevention and control
syphilis	spirochaete bacterium (*Treponema pallidum*)	sexual intercourse with an infected person	highly contagious in its early stages, yet the person may not notice any symptoms; there may be a sore at the place of infection; it later causes sores in the mouth and on the skin; if untreated, may cause anaemia, fever, loss of weight, pain in the bones and joints and may eventually lead to paralysis and insanity	avoiding casual sex; wearing a contraceptive sheath; can be treated with antibiotics in the early stages
gonorrhoea	coccus bacterium (*Neisseriae gonorrhoea*)	as for syphilis	white discharge from the urethra and burning sensation when passing urine; if untreated, the symptoms may subside after 2–3 months but the infection may cause permanent sterility; may also affect the eyes of babies at birth as they pass out of the genital tract of the mother	as for syphilis
chlamydia	chlamydia bacterium (*Chlamydia trachmatis*)	as for syphilis	inflammation of the urethra in males and the urethra and cervix in females. In many cases there are no obvious symptoms, so the infection goes untreated and is spread; the Chlamydia bacterium can infect and block the uterine tubes, resulting in sterility; chlamydial infection can cause eye infection in infants born to infected mothers.	as for syphilis
AIDS (Acquired Immune Deficiency Syndrome)	virus (human immuno-deficiency virus – HIV)	intimate sexual contact with infected person; mixing of infected blood or body fluids with another person's, for example drug addicts sharing needles	breakdown of natural immunity to disease; person succumbs more readily to diseases like pneumonia and a certain type of skin cancer; the virus can remain 'hidden' in the body for several years; can be passed to babies in the womb or through breast milk	avoiding intimate sexual activities, particularly in a homosexual relationship; not sharing needles; as yet there is no cure for AIDS; much research is going on into developing a vaccine against the virus
genital warts	human papillomavirus (HPV)	skin-to-skin contact during sexual intercourse	genital warts are growths or bumps that appear on the external genitalia, in or around the vagina or anus or on the cervix in females and on the penis, scrotum, groin or thigh in males; the warts are normally painless; in women, genital warts are considered to be a risk factor for certain types of cervical cancer	antiviral drugs can be effective in treatment of the infection

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Table 3.2.4 Sexually transmitted diseases (*continued*)

Disease	Causative agent	Mode of transmission	Symptoms	Prevention and control
grab lice/ pubic lice	arachnids	skin-to-skin contact during sexual intercourse	lay eggs in pubic hair; mouthparts adapted for penetrating the skin and sucking blood and body fluids, a process that causes severe itching	can be controlled through careful hygiene and chemical treatments

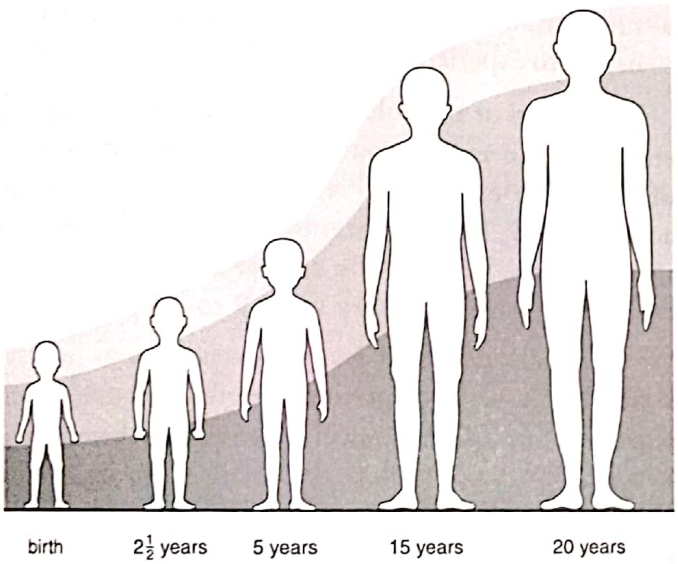


Fig 2.53 The growth pattern of a human.

foetal stage (12 weeks after conception). The foetus is about 76 mm long and weighs about 28 g. The head is large in proportion to the rest of the body. Although the nervous system is still incomplete, by the end of the 16th week the baby begins to make movements, known as 'quickening'.

Though the sex of the child is determined at fertilisation, it can only be seen in the foetus during the last three months before birth. The baby doubles its weight during this time and increases in size by about 50 per cent.

By the last few months of the pre-natal stage, the baby's lungs and digestive system are fully developed. This is why a baby born prematurely can survive, if given special care.

Infancy (birth to 2 years)

A newborn baby seems small and helpless. However, all its senses function and its body is capable of considerable activity. The child displays reflex (automatic) actions like crying, grasping, blinking, sucking and swallowing.

The average weight of a newborn baby is 3.25 kg, with boys being slightly heavier than girls. A baby can usually sit unsupported by the seventh month and crawl by the tenth month. Walking is mastered by fifteen months, though there are differences among children in these developmental levels. The child triples in weight within the first two years and learns to respond more specifically to messages received by the senses than he or she did at birth.

Physically, growth is very rapid initially but slows down in the third year. Cell division occurs all over the body, causing an increase in mass and height but different parts grow at different rates (Figure 2.53). The child's motor abilities begin to develop and he or she can now sit, crawl and walk. The child experiences both physical and mental growth (see page 382).

The muscles also develop. By the end of the first year, the baby's throat muscles, tongue, larynx and teeth have developed sufficiently to turn sounds into speech.

Childhood (2–10 years)

Childhood can be divided into early childhood or pre-school age (2–6 years) and later childhood (6–10 years).

Early childhood or pre-school age

At the age of three years, a child will have reached half its adult height. The child develops physically and mentally, learning to co-ordinate their limbs in activities such as climbing, jumping, running and throwing. A child's speech will improve steadily during this stage and the vocabulary will increase.

The skills acquired by pre-school children make them more efficient and independent in handling their

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own needs such as dressing, using a handkerchief and fastening buttons and zippers. These physical skills are usually mastered very quickly. At age five, all children are very active but vary considerably in their motor skills.

Later childhood (6–10 years)

Children at this stage improve their muscle control as their muscles develop and become better skilled at physical activities. This is the period of 'stability' in the development of a child. The bones become harder and the joints are more closely set; the muscles become firmer, giving greater physical endurance.

At this stage girls grow faster than boys. Boys and girls do not play together as much as they did at an earlier stage. The child at this level shows some curiosity about sex. Answers to questions about sex must be honest and frank.

During this stage the child's mental capacity increases. Children at this stage of development are able to solve simple problems. Children begin to be influenced by their peer group.

Adolescence (11–20 years)

This is the period in a person's life which involves the transition from child to adult. A WHO (World Health Organization) expert committee of 1995 put this period at 10–19 years.

The age of onset of the adolescent period differs according to climate, race, family, socio-economic group and between individuals in the same family. Adolescence can be divided into two parts: the early adolescent period (10–14 years) and the later adolescent period (15–19 years).

Adolescence is both a biological and social process, the onset of which is marked by biological changes in both boys and girls. While the biological adolescent period ends at 19 years, the social adolescent period ends a little later, for example at 23 years, when a young adult is expected to get a job.

The physical changes that take place in an adolescent's body are conspicuous. There is a rapid increase in size, until full adult size is reached in later adolescence.

The early part of adolescence is known as **puberty** and occurs earlier in girls than in boys. The body of the adolescent person at puberty experiences spurts of physical growth, bringing bouts of extreme fatigue and headache.

The adolescent boy becomes more interested in 'male' activities such as sport. The physical changes that take place in the adolescent boy include increased height and muscle mass. The testes and penis begin to enlarge and develop to adult size between the ages of 12 and 13 years. This development completes between ages 15 and 16 years. Other changes include:

- growth of body hair (in the armpits and around the genitals) and facial hair
- voice becomes deeper (voice breaks) as larynx enlarges
- chest and shoulders become broader
- production of the male hormone, testosterone, by the testes
- production of sperm begins – an adolescent male begins to experience wet dreams.

The breasts of an adolescent girl begin to develop and enlarge at the age of around eleven, due to deposition of fat. Girls experience very rapid physical growth, accompanied by the beginning of ovulation and menstruation, between the ages of 11 and 13, though the time of onset can vary from 9 to 16 years. Other changes in girls include:

- body contours become rounded
- growth of pubic hair (in the armpits and around the vulva)
- increase in size of the uterus and vagina
- pelvic girdle enlarges, resulting in wider hips
- production of the female hormone, oestrogen, by the ovaries
- pre-menstrual syndrome (PMS) shown as violent moods and depression.

These changes are referred to as **secondary sexual characteristics**. The onset of puberty is stimulated by hormones secreted by the pituitary gland (page 387).

Other characteristics of the adolescent person include a strong attachment to their peer group, strong emotional feelings and violent mood swings, conformity to group standards and an increased interest in the opposite sex. Delinquency rates are high, while drug- and alcohol-related problems may begin to show. There is a desire for greater freedom and self-expression and frustrations may result from unfulfilled needs.

Adolescents are mature enough to marry at the later stage but often fail to realise that they lack the social, emotional and economic security to be parents. However, most adolescents emerge from this stage as responsible young adults.

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Adulthood (over 20 years)

The stage of adulthood is marked by significant physical and social changes. Adults choose a career, mate and produce children.

Old age

As we grow older, certain physical and physiological changes begin to occur, as a result of decreasing production of sex hormones. Some people go through a decline but others remain active and capable until the end of their lives.

Most of the physical changes associated with ageing begin to appear between the ages of 30 and 40. These include:

- greying hair
- impaired vision due to reduction in the elasticity of the eye lens
- a gradual loss of hearing
- loss of teeth.

The ageing person experiences a gradual decrease in the senses – the ability to taste and detect odours is reduced. Old people become arthritic and find it difficult to get around. Others show some level of mental deterioration (senility) between the ages of 65 and 75 years. The body's ability to combat infection declines because the immune system becomes less effective. In women, the bones lose calcium and become more likely to fracture. Women experience psychological changes like depression, moodiness and fits of crying. Men may experience nervousness, irritability, depression and indecision.

Early parenthood

Babies should be born to mature, well-adjusted parents, living in a secure relationship, who have the means to support and care for the child. Early parenthood is beset by problems associated with immaturity (see page 252).

Several factors can lead to early parenthood:

- **Ineffective parental care** – some parents do not care about the behaviour of their adolescent children. Some adolescents take advantage of this and indulge in immoral acts, including experimenting with sex, leading to early parenthood. Other parents simply cannot control their adolescent children, making it likely that they will end up as young parents.
- **Poor status of parents** – poverty makes it impossible for some parents to care for their families. Teenage girls may be forced into prostitution and may become pregnant. Boys may be neglected and left to fend for themselves. They may become sexually active and end up as young fathers.
- **Peer group pressure** – adolescents often boast about their sexual exploits. These comments, which can be gross exaggerations, influence other, less-experienced, youngsters to experience sex to fit in with their peers. Their inexperience may cause them to end up as young parents.
- **Fashion** – the desire for money and material gains to keep abreast with fashion forces some girls to flirt with rich men, ending up as teenage mothers.
- **Lack of proper sex education** – most boys and girls are not well informed about sex due to lack of communication between parents and children, teachers and pupils and churches and teenagers. Young teenage couples, although sexually active, are often not aware of the consequences of early sex. It is important that parents, teachers and church leaders are frank and honest and talk to teenagers properly about sex to enable them to know how to take precautions to avoid early parenthood.
- **Rape** – if a man has sex with a woman against her will, this is rape. Often this results in pregnancy.
- **Betrothal** – girls are sometimes given in marriage at an early age, for example in childhood. Such girls usually become pregnant as soon as they reach sexual maturity and start to ovulate, hence early parenthood.
- **Marrying too early** – teenage marriages can lead to immature adolescents becoming parents.
- **Media influences** – attending concerts and dances and watching adult films on television, at cinemas and video shows, makes boys and girls want to experience sex and can lead to early parenthood.
- **Curiosity** – some boys and girls hear about sex without knowing exactly what it is. They therefore want to try it but one trial is enough to cause pregnancy.
- **Illiteracy** – many illiterate adolescents are totally ignorant about the problems of early parenthood and often become young parents.

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Table 2.10 Methods of birth control

Method	How used
abstinence	total avoidance of sexual intercourse
coitus interruptus	withdrawal of the penis from the vagina before ejaculation
rhythm method	having sexual intercourse during safe periods only
sterilisation of men	cutting the vas deference and tying them through surgical operation (vasectomy)
sterilisation of women	cutting the oviducts and tying them through surgical operation (tubal ligation)
contraceptive pills	tablets taken regularly by the woman, one a day, for three weeks and stopped for one week during which time menstruation occurs; the pills contain hormones that prevent ovulation
spermicidal creams	creams applied inside the vagina before sexual intercourse; the cream kills sperm
foaming tablets	one tablet is inserted into the vagina before sexual intercourse; the tablet forms a foam that kills sperm
sheath or condom	made of light rubber, rolled on to the penis before having sexual intercourse; it prevents sperm from entering the vagina
IUD (intra-uterine device)	a small plastic loop or coil that is inserted in the uterus by a doctor or qualified nurse; the IUD interferes with and prevents implantation of the fertilised ovum
diaphragm or cap	a dome-shaped rubber structure designed to fit over the cervix; the woman inserts the diaphragm into the vagina before sexual intercourse and removes it 8 hours after intercourse

Teenage pregnancy and early parenthood are contributing to global population increases by as much as 30 per cent. This is a global problem that needs to be addressed.

Family planning

When people marry and want to raise a family, they should plan how many children they wish to have. The number should be manageable, so that they can give each child food, care, attention and opportunities to obtain a life that suits them. Family planning involves spacing out pregnancies so that there is a reasonable gap between each child. To do this, the couple must use some form of birth control which will prevent the woman from becoming pregnant. Different methods of birth control are described in Table 2.10 and illustrated in Figure 2.54.

If birth control is not used, a woman can become pregnant as soon as she stops breast-feeding the previous child. This can mean a new baby as often as every twelve months, resulting in a large family. Many parents are not able to cope with the stresses of looking after several young children and the family income may not be sufficient to feed and clothe them adequately. Where there is insufficient food on the family table, the youngest children often don't get their fair share and consequently suffer from malnutrition. It is difficult for the parents of a large family to give equal care and attention to each child, leading to some children being neglected.

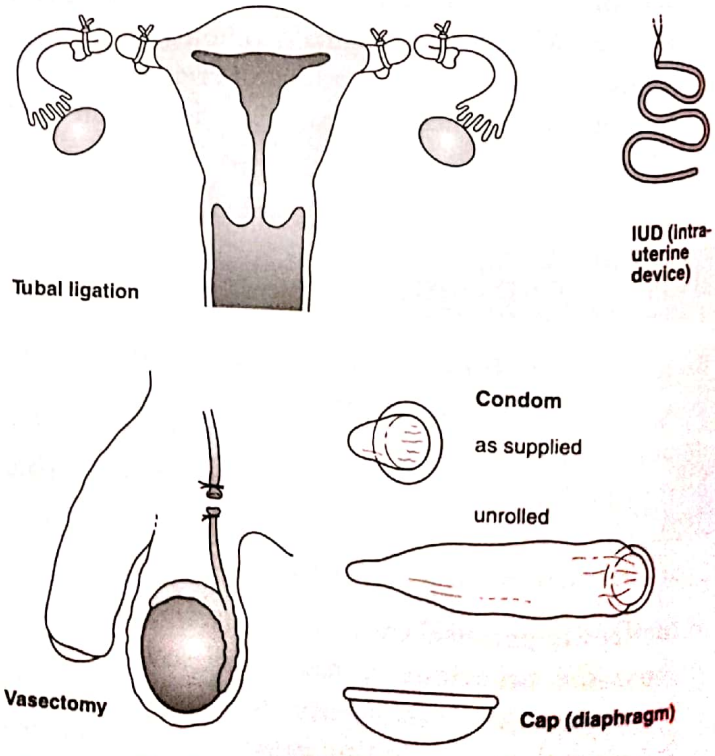


Fig 2.54 Methods of contraception.

Activity 5 Problems associated with large families

Role play the effects of short spacing between children and large families.

The menopause and effects of late delivery on women

Menopause

The menopause is the time during which a woman loses the ability to reproduce. The timing varies greatly in different women. It normally happens at some time between the ages of 42 and 50 years.

Menopause is characterised by:

- ending of ovulation and menstruation
- decrease in size of the breasts, vagina and uterus
- decline in sexual desire
- drying the vagina.

These changes occur as a result of a decline in the production of sex hormones. Some problems associated with menopause are depression, restlessness, hot flushes and mood swings. At the onset of menopause the woman may feel tired and run-down for some months. These symptoms are mostly due to fluctuating hormone levels.

Effects of late delivery

The reproductive period of a human female lasts for about thirty years, that is, from 14 or 15 to about 45 years (from puberty to menopause). It is, however, not advisable for a woman to start to have children towards the end of that period. In fact, it can be risky and dangerous for a woman to have a first child after the age of 35 because the mother may die, there is a risk of the child being mentally retarded or suffering from some other genetic defect and it may be difficult for the couple to look after children when they retire from work.

Self check

For questions 1 to 11, choose the letter that refers to the correct option.

1 Which of the following structures produce the sperm in male mammals?
- **A** epididymis
- **B** seminal vesicles
- **C** seminiferous tubules
- **D** vas deferens

2 The testes of male mammals hang outside the body because
- **A** the temperature inside the body is too low for maximum sperm production
- **B** the temperature inside the body is too high for maximum sperm production
- **C** the scrotal sac lives outside the body
- **D** the testes must hang outside to support the penis

3 Which of the following is the collective name for the group of female sex hormones produced by the ovary of female mammals?
- **A** androgens
- **B** oestrogens
- **C** progesterone
- **D** testosterone

4 One advantage of male circumcision is to
- **A** declare the individual holy
- **B** confer manhood on the individual
- **C** prevent infection of the tip of the penis
- **D** enable the penis to become erect

5 Identical twins look alike because
- **A** they develop from one ovum fertilised by two sperm at the same time
- **B** they develop from two ova fertilised by one sperm at the same time
- **C** they develop from two ova fertilised by two sperm at the same time
- **D** they develop from one ovum fertilised by one sperm

6 Which of the following is the outermost embryonic membrane of the mammalian embryo?
- **A** amnion
- **B** allantois
- **C** chorion
- **D** yolk sac

7 In the study of growth and development in humans, the term 'pre-natal' means the period from:
- **A** fertilisation to birth
- **B** conception to birth
- **C** birth to childhood
- **D** adolescence to adulthood

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8 Infancy in humans refers to the period from
- **A** birth to 2 years
- **B** fertilisation to birth
- **C** conception to birth
- **D** 2 to 10 years

9 The early part of adolescence is known as
- **A** menopause
- **B** gestation period
- **C** puberty
- **D** conception

10 Which of the following sexually transmitted diseases (STDs) is caused by a virus?
- **A** gonorrhoea
- **B** syphilis
- **C** chlamydia
- **D** AIDS

11 The term menopause means
- **A** having the first child after the age 35 years
- **B** the period of development of secondary sexual characteristics
- **C** the period during which a woman loses the ability to reproduce
- **D** the decline of sexual desire in a woman

12 Briefly explain the processes that lead to menstruation in human females.

13 **a)** State the advantages and disadvantages of male and **b)** female circumcision.
c) Why should female circumcision be abolished?

14 Briefly explain the cultural values of circumcision in some communities.

15 Describe the process of birth in humans.

16 **a)** How are the following twins formed?
(i) fraternal twins
(ii) identical twins
(iii) conjoined twins.
b) State two differences between fraternal and identical twins.

17 Explain the importance of pre-natal care of mothers and babies.

18 State four disadvantages of teenage pregnancy and parenthood.

19 State four problems associated with reproduction in humans.

20 Describe three causes and effects of ectopic pregnancy.

21 Explain three causes of infertility in male and female humans.

22 What are the effects of fibroids on fertility in humans?

23 List the phases of growth and development in humans. Briefly explain the physical and behavioural changes in each phase.

24 State the secondary sexual characteristics that appear at puberty in a) boys and b) girls.

25 Copy and complete the table about sexually transmitted diseases (STDs):

Disease	Causative agent	Symptoms	Prevention/ control
(a) gonorrhoea			
(b) syphilis			
(c) AIDS			

26 Briefly explain six factors that lead to early parenthood.

27 Discuss the effects of early parenthood.

28 Describe the symptoms of a woman who is experiencing menopause.

29 Discuss the effects of late delivery on women.

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3 The circulatory system

Learning objectives

After studying this unit, you should be able to:

1 describe the structure and functions of the circulatory system
2 describe the composition and functions of blood and lymph
3 identify disorders associated with blood and the blood circulatory system.

Background information

The food substances absorbed from digestion are needed in all living cells in the body: brain cells, leg muscle cells and kidney cells. In a similar way, the oxygen taken in by the lungs is needed by all the cells.

In smaller animals, such as amoebae, the whole organism is able to obtain food substances and oxygen from its environment by diffusion across the body surface. In larger organisms, like human beings, a great part of the body is far away from the external environment. Therefore, diffusion cannot get food substances and oxygen to all parts of the body. A circulatory system (also known as the transport system) is needed.

In the circulatory system, the heart serves as the 'driver' pumping the blood, which moves the 'vehicle' through blood vessels, which serve as the 'roads'.

Transport in mammals

Structure and function of the heart

The heart is a large muscular organ which is divided into two sides, the right and the left. It is pear-shaped, lies in the thorax between the lungs and is slightly displaced to the left. It has its own blood supply – through the coronary artery and vein – and is made of cardiac muscle.

In longitudinal section, four chambers can be seen – the right atrium, right ventricle, left atrium and left ventricle. The tricuspid valve (with three flaps) separates the right atrium and right ventricle, whilst the bicuspid (mitral) valve (with two flaps) separates the left atrium and left ventricle. Non-return (semi-lunar) valves are found at the base of the pulmonary artery and aorta (Figure 2.55).

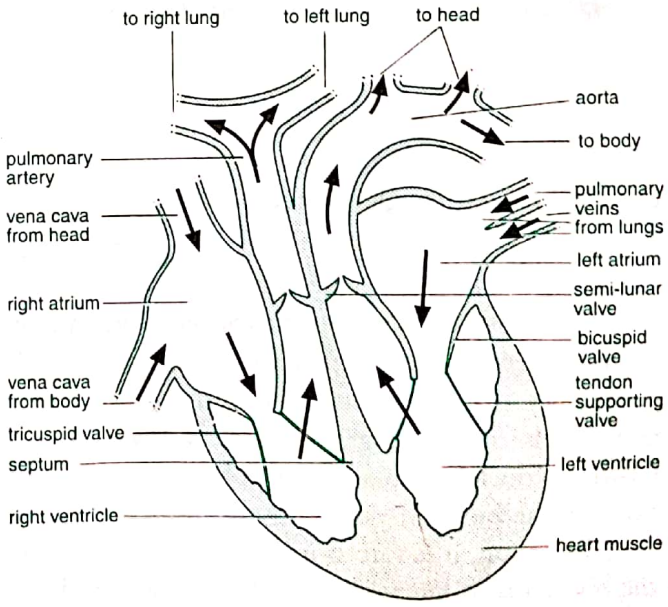


Fig 2.55 Longitudinal section through a mammalian heart showing circulation of blood.

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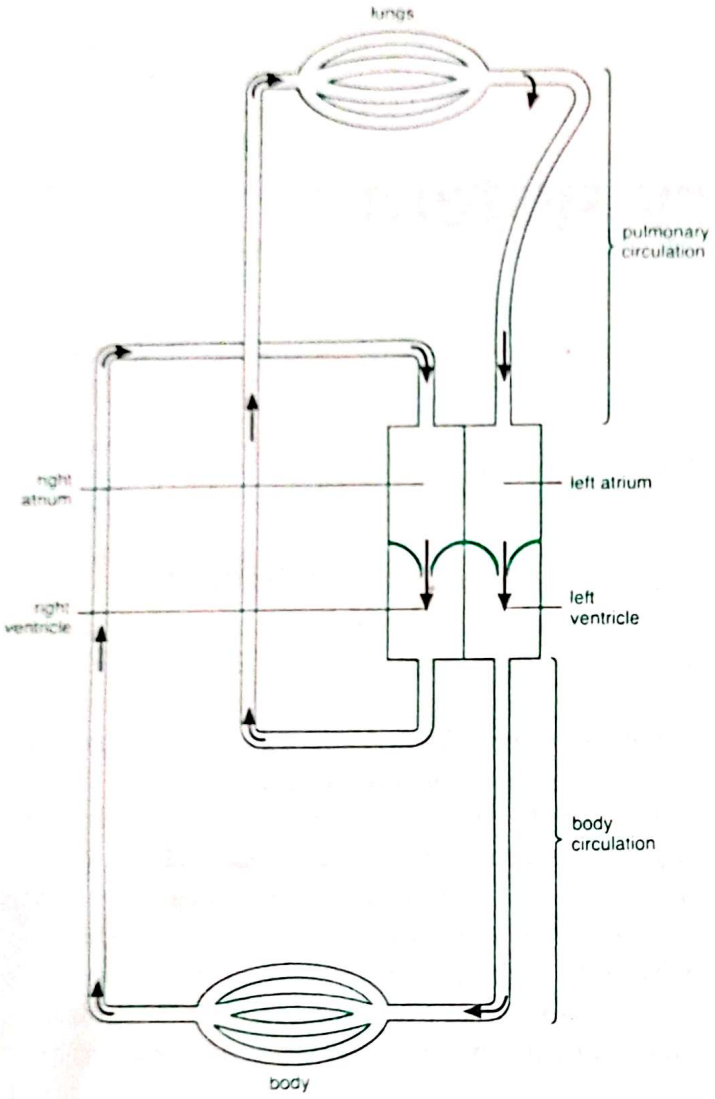


Fig 2.56 Double circulation of blood (diagrammatic).

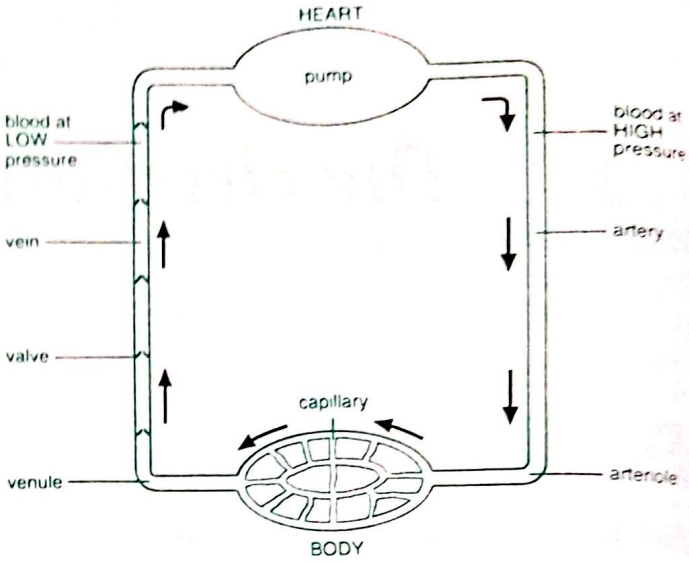


Fig 2.57 Diagrammatic version of blood circulation.

Flow of blood through the heart

De-oxygenated blood from the body enters the right atrium of the heart through the two vena cavae. This blood moves through the open tricuspid valve and into the right ventricle. From there, it is pumped into the pulmonary artery by contraction of the right ventricle and travels to the lungs, where it is oxygenated. It returns to the left atrium via the pulmonary veins, then through the bicuspid valve and into the left ventricle. By contraction, it is forced into the aorta and around the body. This is known as **double circulation**, that is, for every circuit the blood makes, it passes through the heart twice (Figure 2.56).

Blood vessels and circulation

Blood vessels carrying blood away from the heart are called **arteries**. Arteries carry blood under high pressure, which is maintained by the contraction of the ventricles, the elastic tissue in each artery recoiling after it has been stretched and the contraction of muscle fibres in the artery wall.

Arteries branch into thinner **arterioles**, which further divide into **capillaries**, where exchange of substances occurs. The capillaries lead into **venules**, which lead into **veins**, which carry blood back to the heart (Figure 2.57). The differences between arteries and veins are summarised in Table 2.11 and Figure 2.58.

Table 2.11 The differences between arteries and veins

Arteries	Veins
carry blood away from the heart	carry blood to the heart
usually carry oxygenated blood	usually carry de-oxygenated blood
no valves	valves present
smaller lumen	larger lumen
much elastic and muscle tissue	little elastic and muscle tissue
blood under high pressure	blood under low pressure
blood flows in pulses	blood flow is smooth

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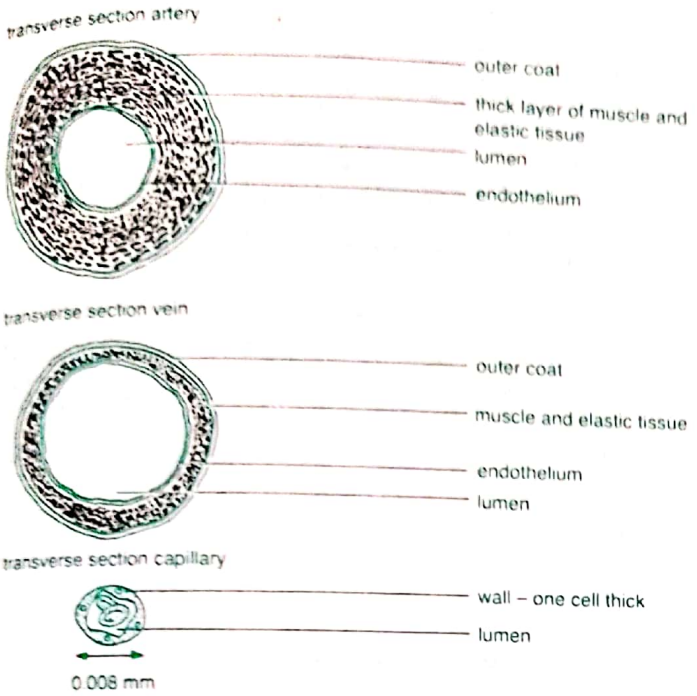


Fig 2.59 Diagrammatic transverse section of artery, vein and capillary.

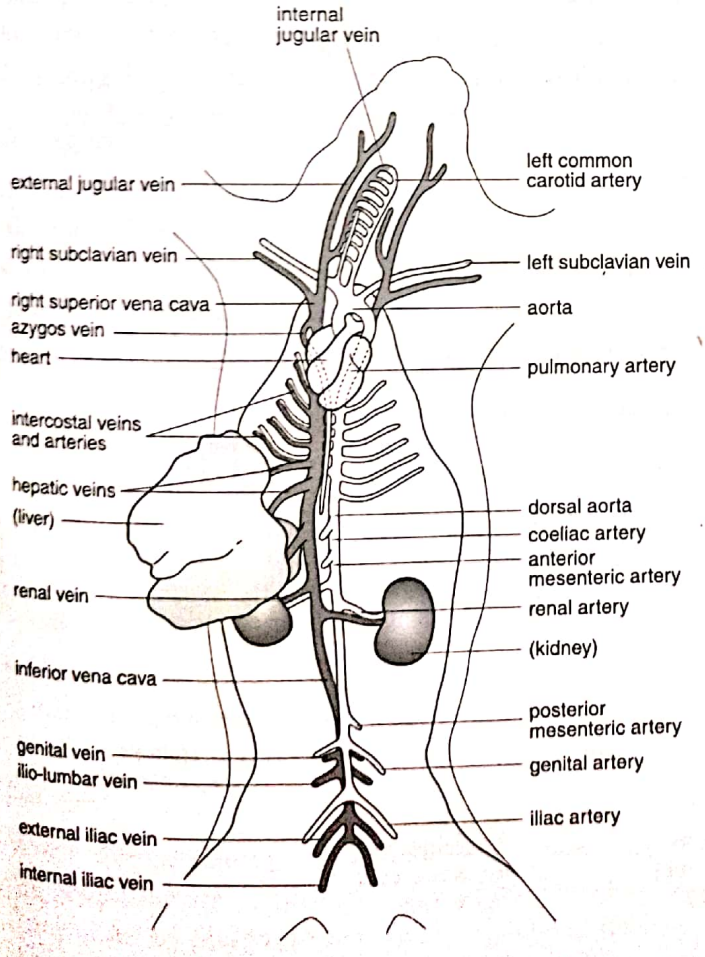


Fig 2.60 The main blood vessels of a rabbit.

ACTIVITY1 Observing the organs concerned with blood circulation in mammals

1 Your teacher will dissect a small mammal, such as guinea pig, rabbit or rat and display the heart and main blood vessels.

2 Critically observe the dissection and identify the heart and main blood vessels using Figures 2.55 and 2.59 as a guide.

3 Draw and label the dissection.

Blood flow is sluggish in veins and it is a problem getting it back to the heart, especially from the lower limbs. Large veins in the legs are squeezed by muscles as they contract. This pushes the blood along. Valves in the veins prevent the blood from flowing in the wrong direction (Figure 2.62).

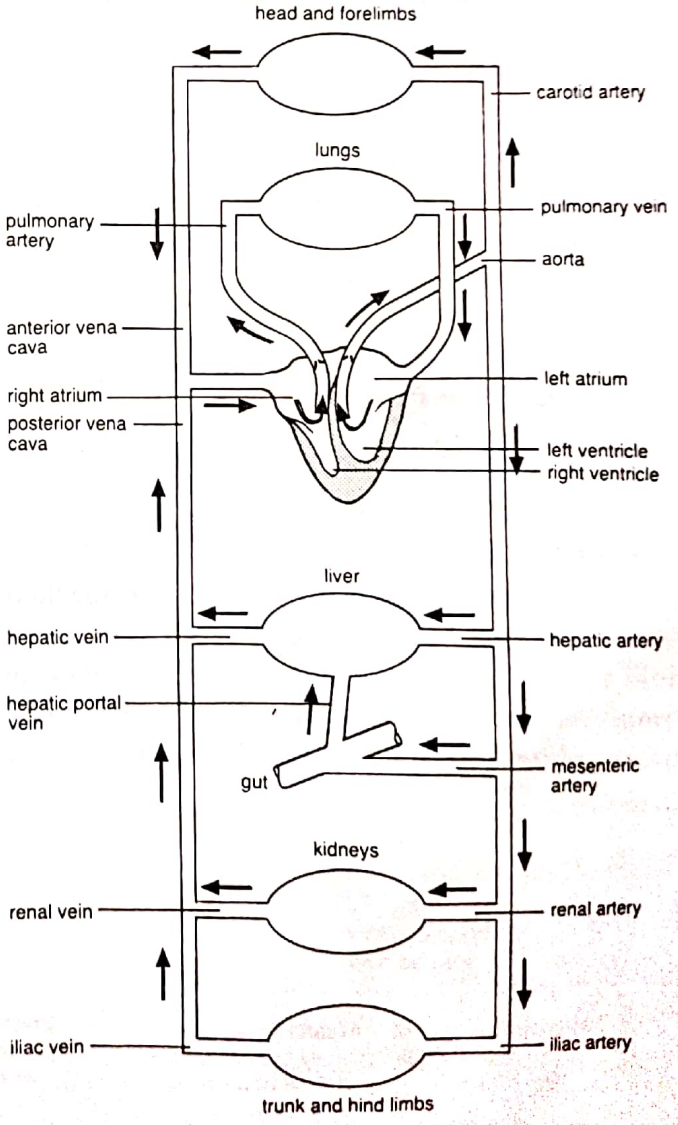


Fig 2.61 Circulatory system of a mammal.

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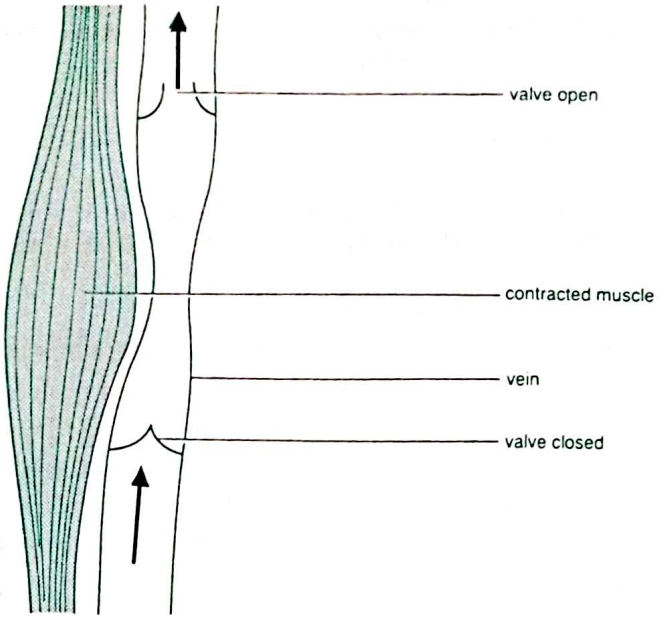


Fig 2.62 Blood flow in veins and muscle action.

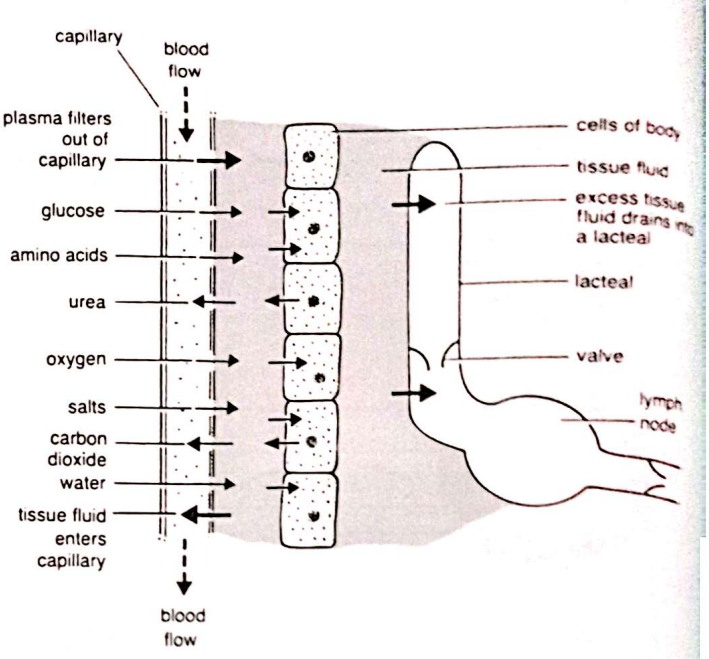


Fig 2.63 Blood, tissue fluid and lymph.

Capillaries

Capillaries are minute tubules (Figure 2.59). Their walls are one cell thick and have minute gaps between the cells. Small substances such as water, salts, gases, glucose and amino acids, can therefore pass out from the cells.

Composition and functions of blood and lymph

Lymph

The fluid surrounding the cells is called the tissue fluid. Substances move into and out of the cells via the **tissue fluid**. Excess tissue fluid drains into a series of tubes, the **lymph vessels**. These join up and form the **lymphatic** system, which drains into the bloodstream in the neck.

Lymphatic fluid is colourless. As well as taking excess tissue fluid back into the blood, the lymphatic system also transports fats (see Year 1, Section 5, Unit 5) and excretory compounds and produces certain types of white blood cells (in the lymph nodes). Figure 2.63 shows the main vessels and the presence of valves.

Blood

Blood is made up of plasma and solid materials, including blood cells (Figure 2.64).

ACTIVITY 2 Looking at blood cells

Caution: Do not prepare a slide of human blood, due to the risk of contracting AIDS.

1 Observe blood cells from a prepared blood slide.

2 Identify the various blood cells observed in 1. Use Figure 2.65 as a guide.

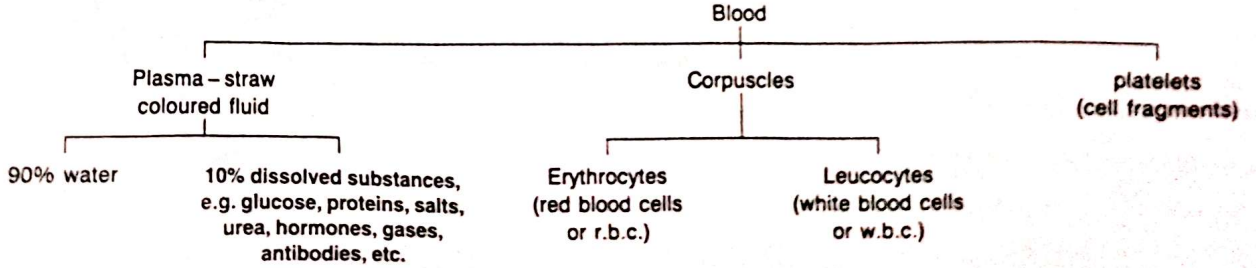


Fig 2.64 Composition of blood.

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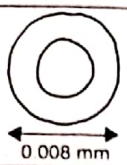
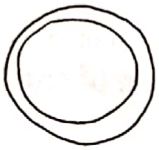
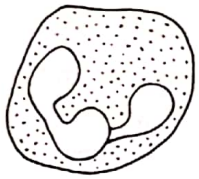
name	appearance	number per mm³	where produced	function	life span
erythrocytes (red blood cells)	 biconcave discs – no nucleus 0.008 mm	approx. 5 million	bone marrow	transport of oxygen	approx. 3 months
leucocytes (white blood cells)	several types  lymphocyte – large nucleus  phagocyte – lobed nucleus and granular cytoplasm	8,000–10,000	lymph nodes and bone marrow	defence against disease	variable – 2 to 3 weeks
thrombocytes (platelets)	 no nucleus – fragments of cells	approx. 250,000	bone marrow	clotting	variable

Fig 2.65 Different types of blood cells.

Blood has three main functions.

Transport

Blood carries many different substances around the body –

- **Oxygen** in the haemoglobin in the red blood cells, as oxyhaemoglobin.
- **Carbon dioxide**, some combined with haemoglobin but most as hydrogen carbonate ions in the plasma.
- Simple **foods**, such as glucose and amino acids.
- **Urea**, made in the liver by breakdown of excess amino acids (see Year 2, Section 3, Unit 1) to the kidneys, from where it is excreted.
- Hormones secreted by the endocrine glands which trigger other organs to act.
- **Heat**: mammals are warm-blooded, that is, they maintain a constant body temperature. Blood carries heat to maintain this temperature.

Defence

When disease-causing organisms (pathogens) enter the body they are attacked by the **white blood cells**. Some work by **phagocytosis** (they engulf and destroy the pathogen), some produce **antibodies** and some produce **antitoxins**. Platelets are important in blood clotting (Figure 2.66). Blood clotting reduces loss of blood, prevents germs from entering the body and helps wounds to heal.

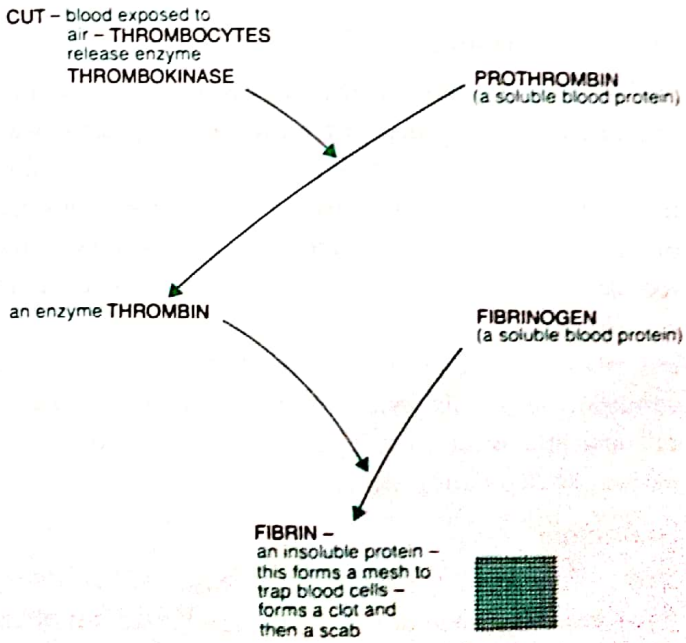


Fig 2.66 The process of blood clotting.

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3 Reproduction

Blood is essential in mammals to make the penis erect so that sexual intercourse can take place (see Year 2, Section 3, Unit 2).

Disorders of the blood and circulatory system

Disorders of the blood

Haemophilia

This disorder is caused by a deficiency in one of the blood clotting factors. People with this disorder bleed excessively when they have a cut because it takes a long time for clotting to occur. It is hereditary (can be passed from parents to children). The individual is said to be **haemophilic**.

Anaemia

This is a decrease in red blood cell production which results in a deficiency in the oxygen-carrying capacity of the blood. Anaemia is a diet-related blood disorder that results from eating food deficient in iron. The individual is said to be **anaemic**.

The disorder can be corrected by eating food which serves as a source of iron, such as green vegetables, eggs, yeast, liver and kidney.

Sickle cell anaemia

Sickle cell anaemia is an inherited disease. It occurs when the normal haemoglobin molecule (A) is replaced by an abnormal haemoglobin molecule (S). The S haemoglobin makes the red blood cells become sickle shaped instead of the normal, rounded shape. The sickle shapes of the red blood cells block the blood capillaries, making blood circulation to the tissues less efficient. Sickle cells are far less efficient at carrying and transporting oxygen. The condition results in severe anaemia. People with sickle cell anaemia must inherit the sickle gene from both parents, so that their genotype is SS.

Leukaemia

This refers to potentially fatal diseases involving uncontrolled growth of the white blood cells. It is often called cancer of the blood.

Hypercalcemia

This is a condition of too much calcium in the blood.

Myeloproliferative disorders

This refers to a group of disorders characterised by abnormal proliferation of one or more types of the bone marrow cells.

Disorders associated of the blood circulatory system

High blood pressure (hypertension)

High blood pressure is due to the reduction in the diameter of the arteries, which causes the blood to be circulated at a very high pressure. The heart is forced to beat more quickly and harder than normal. High blood pressure shows as a blood pressure reading above the normal BP of about 120/80 mmHg.

Factors that could increase the incidence of hypertension are smoking, excessive drinking of alcohol, eating too much fatty food, intake of too much salt, frequent and extreme anger and lack of exercise.

Hypertension can lead to heart failure.

Stroke

Stroke occurs when an artery bursts in the brain. This is usually due to high blood pressure and may lead to paralysis in certain parts of the body and the inability to speak and walk.

Coronary thrombosis

This is a blood circulatory disorder which occurs when a thrombus (a blood clot, called an *embolus* if it moves through the blood vessels) blocks the coronary arteries (that is, the arteries that supply the heart muscles with oxygenated blood). As a result, the heart is deprived of oxygen. Coronary thrombosis causes heart attack.

Low blood pressure (hypotension)

Low blood pressure is a condition that reduces the cardiac output (amount of blood pumped by the heart). The blood pressure may be 90/60mmHg or less.

Low blood pressure may be caused by slow heart rate (*bradycardia*) or the weakening of the heart muscle with age. Other causes of low blood pressure are serious injuries, serious illness, diabetes mellitus and certain medications.

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Symptoms of low blood pressure include light-headedness, blurred vision, palpitations, nausea, general weakness, confusion and temporary loss of consciousness.

Hypotension can lead to heart failure and heart attack.

Hole-in-heart

This is also known as **septal defect**. The term refers to defects in the partitions (septum) which separates the two sides of the heart.

There are two types of septal defect: ventricular septal defect (VSD) and atrial septal defect (ASD). These are defects in which there is a hole in the septum. This may cause severe heart failure.

In a person with a septal defect, instead of going out to the body through the aorta, some oxygenated blood is forced from the left to the right side of the heart through the septal hole, so that too much blood passes into the lungs and too little to the tissues.

In most cases, this is a congenital defect (present at birth). It affects 150 babies in every 100 000. Heart attack can also tear a hole in the septum.

Septal defect can be corrected through open heart surgery or in a key-hole procedure.

Self check

For questions 1 to 16, choose the letter that refers to the correct option.

1 The tricuspid valve of the mammalian heart is located between the:
- **A** right atrium and right ventricle
- **B** left atrium and left ventricle
- **C** right atrium and left ventricle
- **D** left atrium and right ventricle

2 The semi-lunar valves are located:
- **A** at the base of the vena cava and pulmonary artery
- **B** at the base of the vena cava and pulmonary vein
- **C** at the base of the pulmonary artery and aorta
- **D** between the left ventricle and the right ventricle

3 The hepatic portal vein carries blood from the:
- **A** gut to the liver
- **B** heart to the lungs
- **C** liver to the gut
- **D** lungs to the heart

4 Which of the following is not a blood disorder?
- **A** Sickle cell anaemia
- **B** Hole in the heart
- **C** Haemophilia
- **D** Leukaemia

5 A patient with a blood pressure reading of 200/120 mmHg is likely to be suffering from:
- **A** Hypotension
- **B** Cardiac arrest
- **C** Stroke
- **D** Hypertension

6 Which of the following statements is not true?
- **A** An individual who has sickle cell anaemia has an AS genotype
- **B** A person suffering from low blood pressure may have a BP of 90/60mmHg or less
- **C** Stroke occurs when an artery in the brain bursts
- **D** Haemophilia is an inherited disease

7 State two examples of diffusion in animals.

8 **a)** Draw a large labelled diagram of a longitudinal section through the mammalian heart.
b) Use arrows to show the path taken by blood through the heart.

9 What do you understand by the term 'double circulation of blood'? Illustrate your answer with a diagram.

10 Draw a diagram to show the circulatory system of mammals.

11 **a)** Name the components of blood.
b) State the functions of blood.

12 **a)** Name three disorders of the blood circulatory system.
b) Describe briefly the causes and symptoms of any two.

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1 Electrical energy

Learning objectives

After studying this unit, you should be able to:

1 describe static and current electricity
2 mention the various components of electric circuits and state their functions
3 calculate resistance, current, potential difference and power
4 demonstrate the processes involved in electric power generation
5 describe the stages of electric power transmission.

Background information

Electrical energy is one of the most convenient energies that can be tapped, conserved and transported to neighbourhoods and far-away communities for use. The human body has electrical impulses in the nerves which help it to work effectively. Hydroelectric energy, solar energy and biomass provide energy in the fields of work, entertainment, education, health and agricultural processes.

Lack of energy is a sure path to poverty. Efforts aimed at providing energy are also a positive step towards reduction of poverty.

Industries and households rely on the availability of electricity at the touch of a switch. Generating cheaper electricity has become a primary concern for many nations.

Sources of static electricity

In the dry, *Harmattan*, season, crackling noises and sparks (which can be seen in the dark) are produced when hair is combed with a plastic comb. These are due to **static electricity** produced by friction between the plastic comb and the hair. The hair and the comb both become electrically charged. How does this occur?

When we rub one material on another, such as glass on silk, we transfer electrons from one to the other: one acquires a positive electrostatic charge and the other a negative electrostatic charge. The charged bodies attract each other. A charged body attracts bodies that are oppositely charged and repels bodies that carry a similar charge. A charged body also attracts a neutral (uncharged) body.

The separation of charges between two charged bodies creates a difference in potential energy, or **potential difference** (p.d.): the greater the charge, the greater the potential difference. The unit of potential difference is the volt (V). The potential difference between two charges increases with the separation.

The production of charged bodies gives rise to static electricity. We can release the potential energy of this static electricity by placing a link such as a conductor between two oppositely charged bodies, so that electrons can flow from one body to the other under the potential difference.

ACTIVITY 1 Investigating the action of charged bodies on other bodies

1 In dry weather, use a plastic comb to comb your hair.
2 Quickly bring the comb near some small bits of paper.
3 What happens to the paper? Do the pieces of paper stick all the time to the comb? Explain the action.

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ACTIVITY 2 Charging an object by rubbing

1 Rub a glass rod with amber or polythene
2 Place the glass rod in a stirrup and suspend on a thread using a clamp stand
3 Rub another glass rod with a flannel duster or tissue paper
4 Place the second glass rod close to the suspended charged glass rod
5 Record and explain your observation.

You will observe that the comb attracts the pieces of paper. This happens because the rod becomes electrostatically charged. The unlike charge produced from rubbing the glass rods with amber or a flannel duster causes the suspended rod to attract the second rod.

Lightning

On thundery days the clouds become charged by various methods, including the friction between two clouds. The charges result in a relative potential difference between the clouds and the Earth, leading to discharge, which causes lightning and thunder. Thus lightning is caused by electrostatics. In a spark of lightning, a huge current flows, which can strike buildings and coconut or other tall trees and cause fires.

Tall buildings, such as church towers and multi-storey buildings must be safeguarded from lightning strike. Scientists have observed that the charge from lightning can be conducted across curved sharp metal surfaces high in the air. So, buildings are protected with lightning conductors, which are sharp metal rods installed at the highest point of the building and connected through wires to large metal plates in the ground (Figure 2.67).

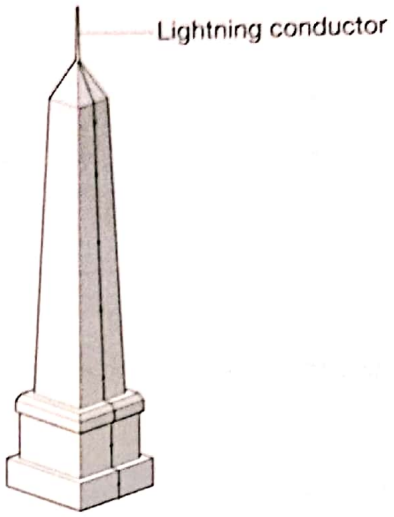


Fig 2.67 A lightning conductor.

ACTIVITY 3 Searching for lightning conductors in buildings

Work in groups to investigate the components of lightning conductors on building such as cathedrals and multi-storey buildings. In your investigation, focus on:

1 The type of metal used
2 The shape of the metal at the top of the building, down the building and in the ground
3 How the lightning is directed from the air into the ground.

Sources of electric current

Sources of electric current (Figure 2.68) include:

- Dry (Voltaic) cells
- Wet (Leclanché) cells
- Secondary (rechargeable) cells

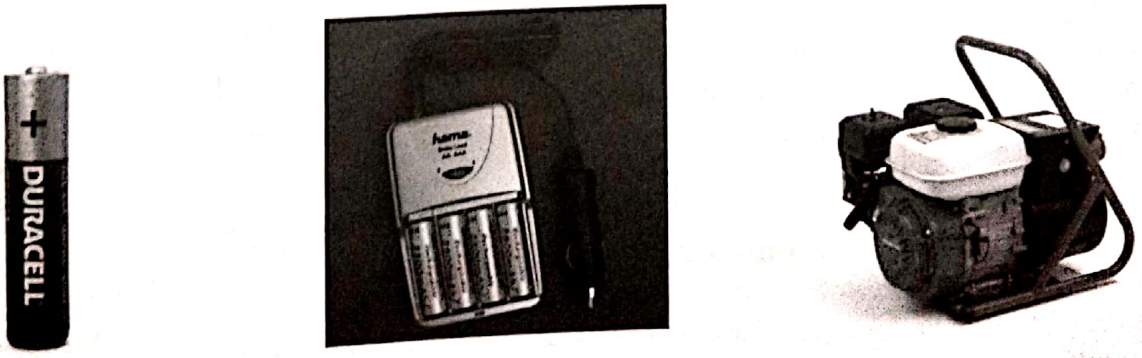


Fig 2.68 (a) Dry (Voltaic) cell (b) Secondary (rechargeable) cell (c) Generator.

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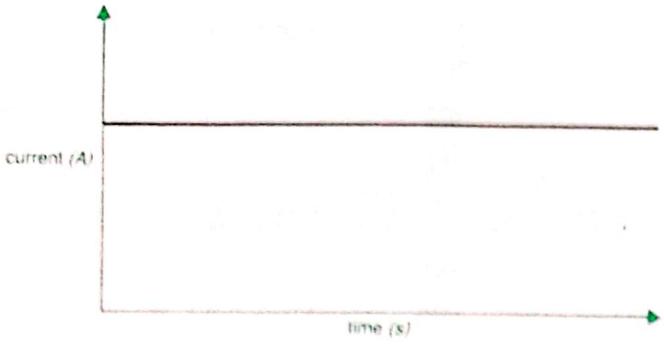


Fig 2.69 Graph of direct current.

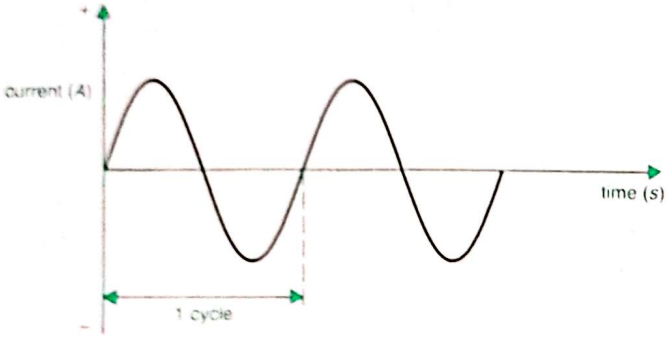


Fig 2.70 Graph of an alternating current.

- Solar cells
- Generators.

Cells transform chemical energy into electrical energy. The electromotive force drives the electrons through the conductors and appliances, forming an electric circuit.

Differences between alternating current and direct current

An electric current in which all the charges flow in one direction is called **direct current** (Figure 2.70). It is often written simply as **DC.** A direct current flowing at a constant value through a coil produces a magnetic field whose size and polarity do not change. Such a current does not induce a current in any other coil or conductor positioned within the magnetic field.

An electric current whose magnitude and direction vary is called an **alternating current** (Figure 2.69). It is often written simply as **AC.** The current starts at zero, builds up to a maximum value in one direction, falls back to zero, then builds up to a maximum value in the opposite direction and so on. This regular waveform is often described in terms of its **frequency**: the number of complete cycles the wave goes through in one second. Mains electricity has a frequency of 50 cycles per second. Cycles per second are measured in **Hertz** (Hz), so the current is at 50 Hz. An alternating current generates a magnetic field whose shape and polarity continuously changes as the current in the wire changes. A current is induced in any other coil or conductor within this magnetic field. The frequency of the current in the secondary coil is the same as that in the primary coil.

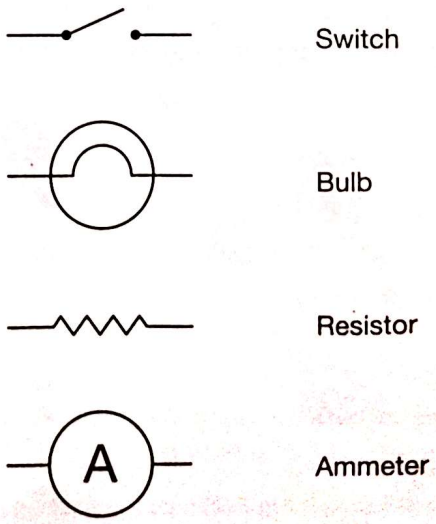
Electric circuits

Electric circuits, both simple and complex, must have a source of electric current – this provides the force needed to move the charges through the conductor – and conducting material. The symbols used in electric circuits are shown in Figure 2.71. Components (such as cells or resistors) in circuits can be set up in **series** or in **parallel**.

Potential difference is the energy used to move a charge between two points. It is measured in volts (V). **Electromotive force** (emf) is the potential difference between the terminals of the cell when no current flows. It is also measured in volts.

The current in a circuit flows from the positive terminal through the circuit and back to the negative terminal. The direction of flow of current is indicated by an arrow.

Circuit symbols



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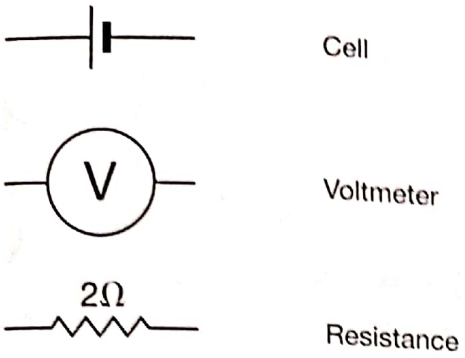


Fig 2.71 Circuit symbols

Cells in series

Cells connected in series form a **battery** (Figure 2.72) and have an electromotive force equal to the sum of the capacity of cells involved.

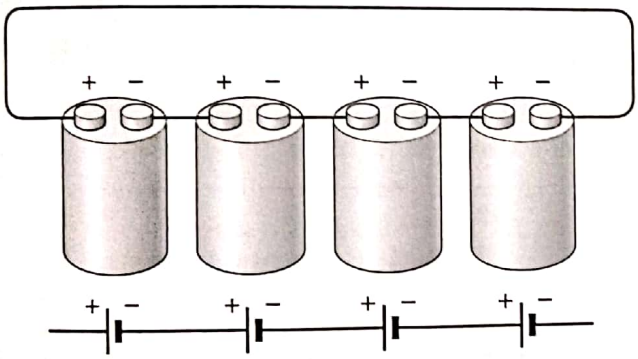


Fig 2.72 Cells in series.

Cells in parallel

Cell connected in parallel (Figure 2.73) have a total electromotive force equal to one of the cells.

Resistors

The connecting materials, the load and the fuses in a circuit oppose the free flow of electric current. Resistors and fuses are intentionally placed in a circuit to reduce the flow of current. Resistors control the flow of current in circuits and transform some the energy flowing through the circuit into light, sound or heat.

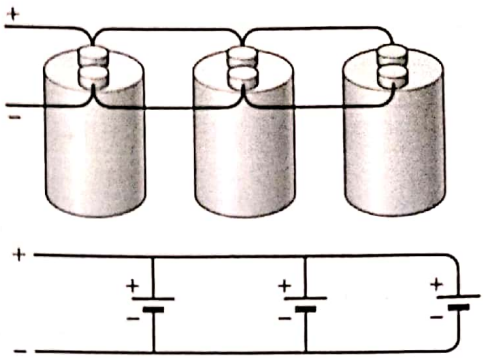


Fig 2.73 Cells in parallel.

The **resistance** of a material is determined by the length of the material, its cross-sectional area and its resistivity. Resistance is measured in Ohms (Ω). A **rheostat** is a variable resistor, used to regulate the flow of current. Rheostats are used on volume control knobs in radios and televisions and to control the speed of ceiling fans.

Ohm's Law

Ohm's Law states that the current (I) flowing through a metallic conductor at a constant temperature is proportional to the potential difference (V) between its ends. Ohm's law is mathematically expressed as $V = IR$, where V is the pd between the ends of the conductor, I is the current and R the resistance of the conductor.

Verification of Ohm's Law

The circuit in Figure 2.74 can be used to verify Ohm's Law.

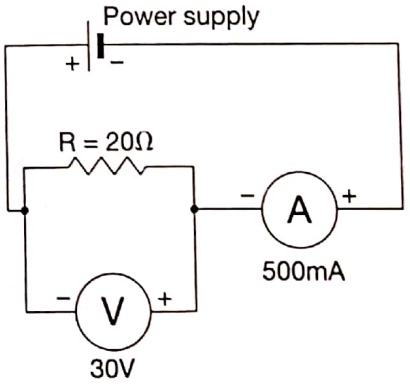


Fig 2.74 Circuit to verify Ohm's Law.

Use the voltmeter to read the p.d. across the resistor and the ammeter to read the current in the circuit. Use the rheostat to vary the current. Record the value of the p.d. in a table.

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Table 2.12

I/A	*p.d*/V

The linear relationship shows that V is proportional to I, that is, $V = IR$

Worked example 1

A 5 Ω resistor has a current of 2 A flowing through it. Find the potential difference across the resistor.

Solution

Resistor = 5 Ω Current (I) = 2A

$V = IR$

$V = 5 \times 2$

$= 10$ V

Worked example 2

Three resistors, of resistance 1 Ω, 3 Ω and 4 Ω respectively, are connected in series to a 12 V battery of negligible internal resistance. Calculate the current flowing through each resistor.

Solution

Total resistance = 1 Ω +3 Ω + 4 Ω

$= 8\ \Omega$

Current (I) $= V/R = 12/8$

$= 1.5$ A

Resistors in parallel

In parallel connection of resistors (Figure 2.75), the current is shared by the resistors according to their individual resistance. The total current flow is the sum of current flowing through each resistor.

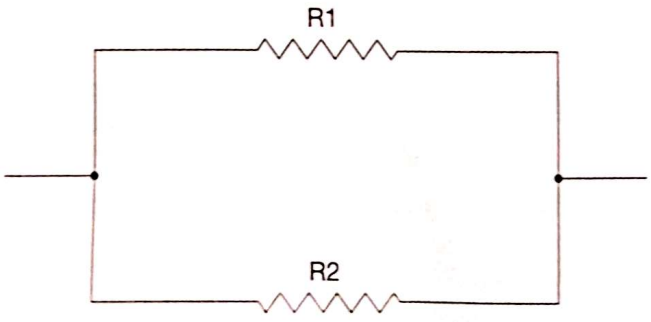


Fig 2.75 Resistors in parallel.

$I_1 = V/R_1, I_2 = V/R_2, I_3 = V/R_3$

But

$I = I_1, + I_2 + I_3$

$V/\mathrm{R}_1 = V/R_1 + V/R_2 + V/R_3$

Dividing both sides by V

$1/R = 1/R_1 + 1/R_2 + 1/R_3$

Resistors in series

When resistors are connected in series (Figure 2.76), the same quantity of current flows through them. The total resistance is the sum of the value of the individual resistors in the circuit. However, a break in one of the resistors creates an open circuit and stops the flow of current in all the other resistors. The potential difference across all the resistors is the sum of the potential difference across each resistor: $\Sigma V = IR_1 + IR_2 + IR_3 \ldots$

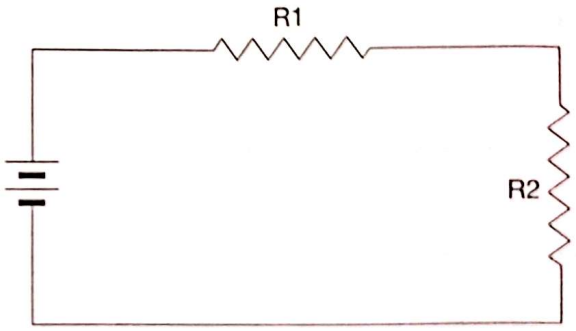


Fig 2.76 Resistors in series.

The resistors are connected together one after the other and there is just one path for the current. The same current flows through each resistor in the circuit. The voltmeter measures the potential difference (p.d.) across each resistor.

Measuring resistance

The Wheatstone bridge is an apparatus for measuring resistance (Figure 2.77). It comprises two parallel resistance branches, with two resistors in series in each branch. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown resistor. If the ratio of the two resistances in the known leg (R_2/R_1) is equal to the ratio of the two in the unknown leg (R_x/R_3), then the voltage between the two midpoints (B and D) will be zero and no current will flow through the voltmeter. At the point of balance, the ratio of $R_2/R_1 = R_x/R_3$

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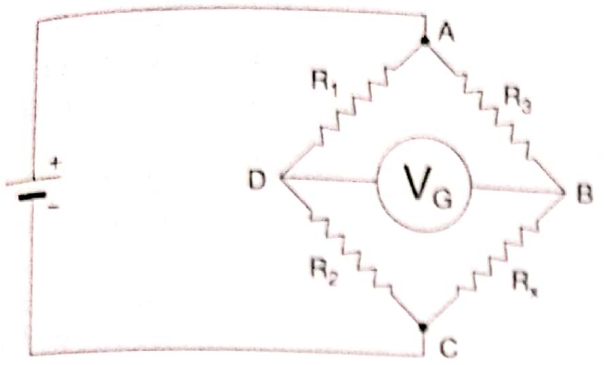


Fig 2.77 The Wheatstone bridge.

Worked example

Resistors of 2 Ω, 4 Ω, 6 Ω, 8 Ω are connected in parallel. What is the total resistance in the circuit?

Solution

In parallel connection

$1/R = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$

$1/R = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} + \frac{1}{8}$

$= 12 + 6 + 4 + 3/24$

$= 25/24$

$= 1\frac{1}{24}\ \Omega$

$= 1.042\ \Omega$

Electric current is measured in **amperes** (A); it is a measure of the rate of flow of electrical charge. Charge is measured in **coulombs** (C). A current of 1A means that one coulomb of charge flows each second.

When charge flows in a circuit, **work** is done. This involves the conversion of electrical energy into other forms of energy. The potential difference between two points in a circuit is 1V if one Joule (1J) of electrical energy is converted to another form of energy when 1C of charge passes from one point to the other.

The p.d. (V) is defined as the energy given out (E) per unit charge (Q):

$V = E/Q$

Electric current (I) is the charge (Q) passed per unit time (t):

$I = Q/t$

Power (P) is the rate of consumption of energy; the amount of energy given out or consumed per unit of time:

$P = E/t$

$I = Q/t$, $Q = It$

$V = E/Q = E/It$

$P = E/t$, therefore $V = P/I$, hence $P = IV$

Electric power

Electrical devices are rated in Watts. An incandescent bulb rated 100 W produces more light energy than a similar bulb rated 60 W. An electric stove is rated 750 W. The power rating of an electrical appliance is shown on the box and on the appliance. This gives an indication of how much power the appliance will consume in a given unit of time.

ACTIVITY 4 Investigating the electric appliances in the home

1 Work in pairs find the electrical ratings of:
   - **a)** An electric iron
   - **b)** A television
   - **c)** A radio speaker
   - **d)** An electric kettle
   - **e)** An immersion heater

2 Visit the office of the electricity company and collect copies of their brochure on the ratings of various appliances. Discuss the consequences for energy consumption of using these appliances for a month, three months and one year.

3 List ten rules that can help households to conserve energy.

Electric power generation

Electricity can be generated by various processes.

In Ghana, **hydro-electric power** is generated from the Akosombo and Kpong hydro-electric dams. It will soon be produced from the Bui dam.

Solar cells convert solar energy (energy from the sun) into electricity. They are used to power communication gadgets, electronic calculators and digital watches.

In some countries, electricity is being produced from **tidal energy**, in which the energy of the waves operates dynamos which generate electricity.

Geothermal energy from the core of the Earth is harnessed to generate electrical energy.

Nuclear energy is a source of electrical energy in Germany, Russia and some other European countries.

Thermal energy, created by burning oil, natural gas, lorry tyres and highly inflammable substances such

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as liquefied petroleum gas (LPG) is used in Ghana to generate electricity at Aboadze near Takerodi in the western region.

Wind energy is converted into electricity in huge turbines. In **windmills**, wind energy is used to pump water or crush grain.

In Apollonia near Dodowa, human and animal wastes are converted into **biogas**. This biogas is used to fuel generators to produce electricity for the domestic activities of the village.

Power transformation and transmission

Transformers are devices in which AC passing through a primary coil induces AC in a secondary coil. We shall discuss the significance of this in terms of the national grid later. First, let us look at transformers in more detail.

The coils of a transformer are wound around a soft iron core (Figure 2.78). This core is usually laminated: that is, it is made of many layers held together. This improves the efficiency of the transformer. The frequency of the current in the secondary coil is the same as that in the primary coil.

The coil carrying the source current is called the **primary coil** and the coil in which a current is induced is called the **secondary coil**. The size of the induced current depends on the size of the source current and is a ratio of the number of turns of wire on the primary and secondary coils (the **turns ratio**). That is:

$$\frac{I_p}{I_s} = \frac{n_s}{n_p}$$

where I_p and I_s are the current in the primary and secondary coils and n_p and n_s are the number of turns in the primary and secondary coils.

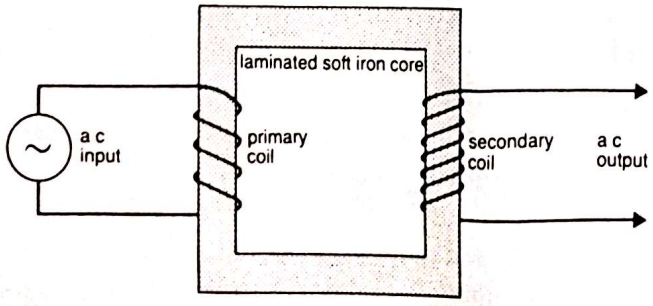


Fig 2.78 A transformer.

Electrical energy cannot disappear. Whatever energy passes through the primary coil must be available to the secondary coil (most transformers are very efficient and very little energy is converted to heat).

We can compare the electrical energy in the primary and secondary coils because the power in the primary and secondary coils should be the same. Suppose we have a transformer in which the primary coil carries a current of 1 A at a potential difference of 240 V. The power in the primary coil will be $1 \times 240 = 240$ W. The power in the secondary coil must also be 240 W. If the secondary coil carries a current of 2 A, the voltage across the secondary coil must be 120 V.

1×240	=	2×120
Primary coil		secondary coil

Transformers transform not only the magnitude of the current but also the voltage. It is not possible to change one without changing the other.

Transformers that convert a low voltage into a higher voltage are called **step-up transformers** and transformers that convert a high voltage into a lower voltage are called **step-down transformers**. The current is stepped down when the voltage is stepped up and stepped up when the voltage is stepped down.

In an ideal transformer (one that wastes no energy), the voltages and the number of turns on the coils are related by the equation:

$$\frac{\text{primary (input) voltage}}{\text{secondary (output) voltage}} = \frac{\text{number of turns on the primary coil}}{\text{number of turns on the secondary coil}}$$

This can simply be remembered as:

Voltage ratio = Turns ratio

It doesn't matter which coil you put on top, but it must be the same for both voltage and number of turns.

When current flows through a conductor, some of the electrical energy is converted into heat energy, which is transferred to the environment. Transformers are never 100% efficient. The amount of energy converted depends on the current through the wire and on the time during which the current flows.

When transmitting electrical energy from a power station to the home, it is important that as little as possible is lost as heat energy. The electricity is transmitted at a very high voltage and therefore a very low current. The lines of the national grid carry electricity at 400 kV. Electricity at this very high

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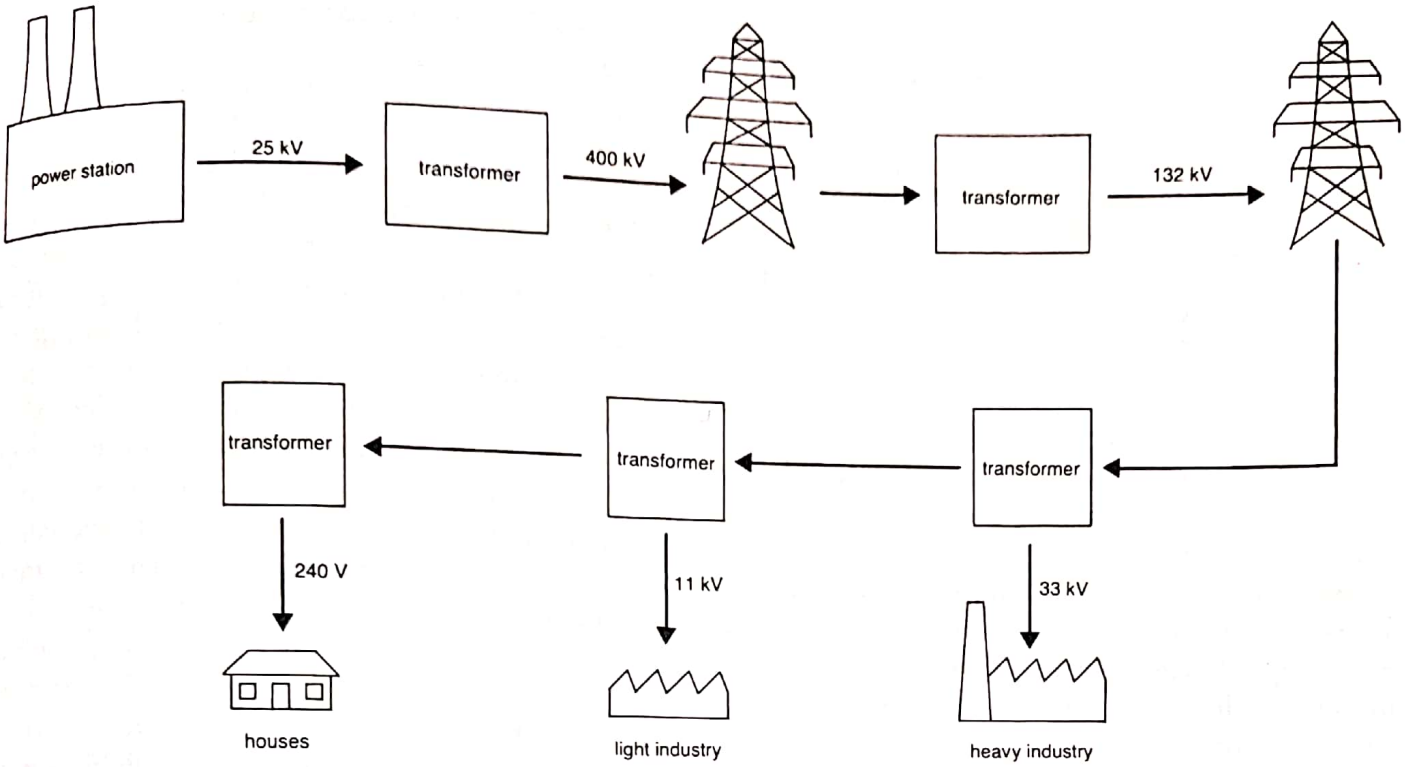


Fig 2.79 The national grid distribution network.

voltage is far too dangerous for use in the home, so it is transformed into a much lower voltage. The electricity that comes into our homes is at 240 V. This transformation occurs in local electricity sub-stations (Figure 2.79). In some countries, such as the USA, the electricity that goes into homes is at 110 V.

Household wiring

Electricity in the house is supplied by a local power station or from the local substation of the national grid system. Thick underground cables or thick overhead wires bring power to the house; this is called the **mains**. Mains consists of two wires: a **live** wire carrying the

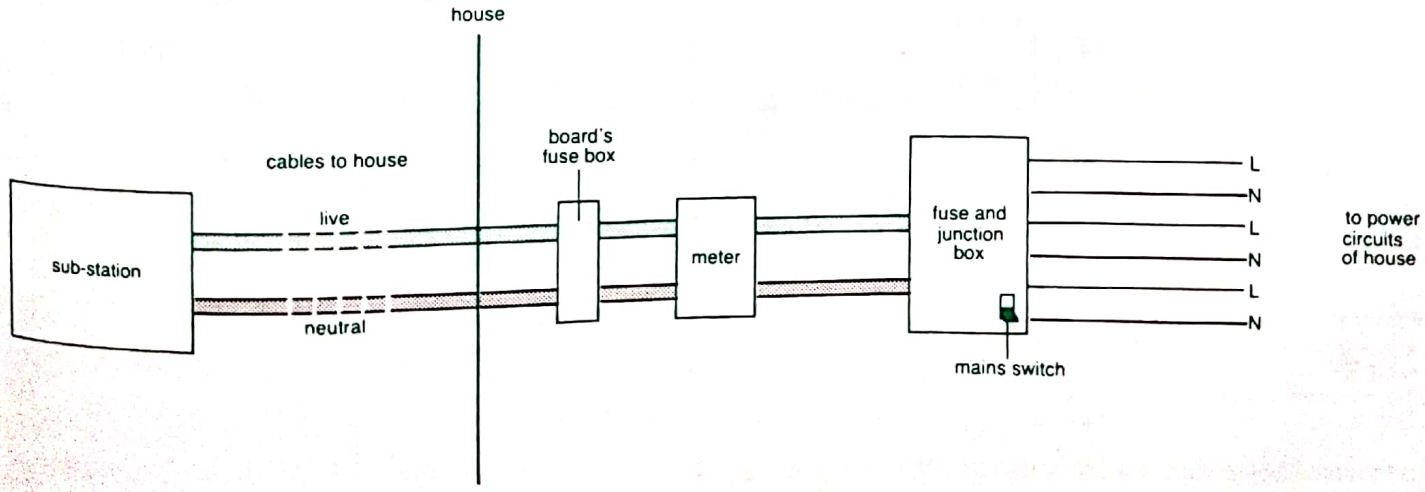


Fig 2.80 Electricity cables entering the house.

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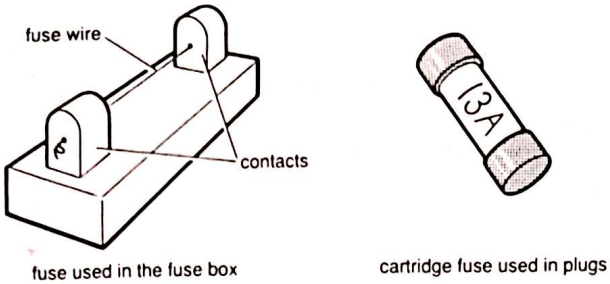


Fig 2.81 Fuses.

full voltage supplied by the generator and a **neutral** wire earthed at the local transformer substation and therefore of zero potential difference (Figure 2.80).

The supply passes through the main fuse, the electricity meter, the main switch and the fuse box. The fuse box contains **fuses**. The job of the fuse is to protect the wiring in the circuit from damage. Different circuits are used for heating, lighting and power. A fuse is a short length of wire made of a metal with a low melting point (Figure 2.81). If the current in a circuit becomes too high, the fuse melts and breaks the circuit and stops the current from flowing. As well as the fuse in the fuse box, which protects the circuit as a whole, each plug that connects an appliance to the circuit also has a fuse, so that if the appliance overloads, the resulting power failure is usually confined to that appliance.

A ring circuit

A **ring circuit** (Figure 2.82) is a cable taken to various parts of the house. Both ends of the cable are connected to the mains. The cable has three wires: live, neutral and earth. Any appliance can be plugged into the circuit and the current has two paths to the live wire and two paths to the neutral. In this way, the appliance is connected to the mains by a cable that has twice the cross-sectional area, and hence half the resistance, of the actual cable used. This means that thinner, cheaper, cable can be used.

The ring circuit allows appliances to be used in parallel with the supply. Lighting circuits are also parallel circuits, so all light bulbs receive the same supply. Why would it be unsatisfactory to wire light bulbs in series?

Switches must be placed in the live wire so that the component or appliance will not be live when the switch is off. Fuses are also placed in the live wire so that if they blow they cut off the dangerous live connection. Appliances that have an outer metal casing are connected to a third wire, the **earth** (the third and largest pin on the plug). The earth wire is there to protect the user: if something goes wrong and the casing becomes live, the earth wire provides a safe route for the electricity to flow along. This prevents the user from getting a shock and will usually result in the fuse blowing.

Household wires are covered in insulating material and are sometimes passed through conduits in the walls of the building. The conduits are tubes made of insulating material such as plastics.

The colour code used for the wires is red (live), black (neutral) and green (earth) or, in the more recently adopted code, brown (live), blue (neutral) and yellow and green stripes (earth) (Figure 2.83). Cables can be

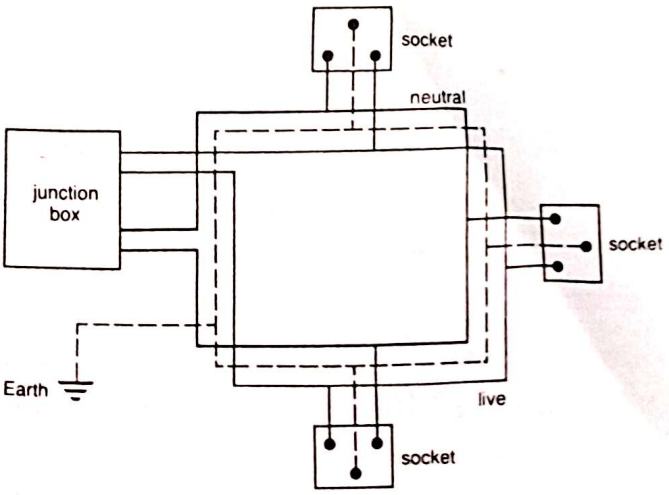


Fig 2.82 A ring circuit.

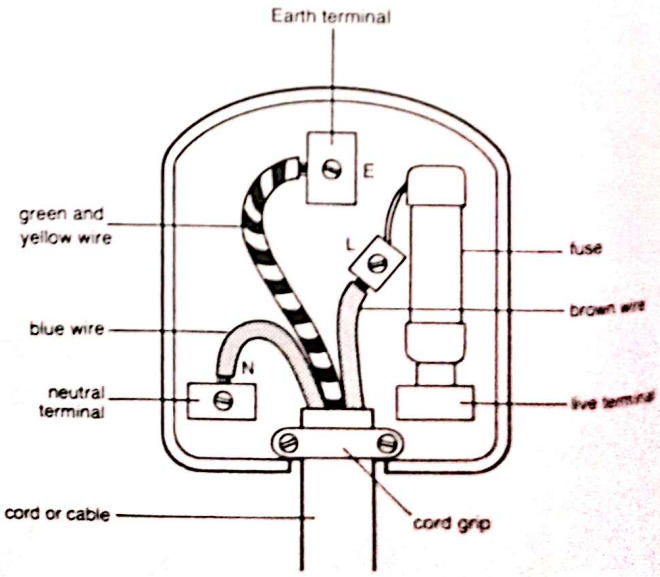


Fig 2.83 The wiring in a modern three-pin plug

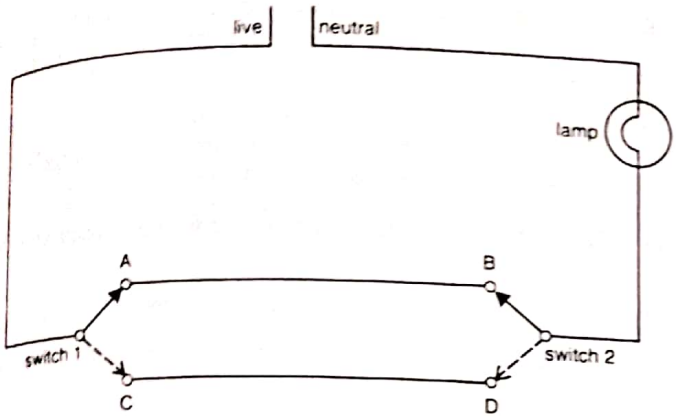


Fig 2.84 A two-way switch.

obtained in both colour codes. The pins of plugs may be square or round and are always thicker than the wires.

Switches

A switch is a control on an electrical circuit. It creates or breaks the circuit. Sometimes, for example on staircases and landings, it is desirable to be able to control lights from two points. This requires a **two-way switch circuit**, shown in Figure 2.84. There are four possible combinations of on/off positions for the two switches:

- When switch 1 is on A and switch 2 is on B, the lamp is on.
- When switch 1 is on C and switch 2 is on B the lamp is off.
- When switch 1 is on C and switch 2 is on D the lamp is on.
- When switch 1 is on A and switch 2 is on D the lamp is off.

ACTIVITY 5 Examining the house wiring

1 Examine the wiring in the laboratory or classroom or at home from the mains to the meter and the fuse box and to the distribution in rooms.

2 Find out whether the supply is from an underground cable or from overhead wires and note the thickness and insulations.

3 Are the wires passed through conduits in the walls or nailed to the walls?

4 Look at the electricity meter. Does it have the older type of clock-face dial, or is it digital?

5 Examine some sockets and plugs used in the laboratory and in the house. What are the voltage markings? Unscrew a 13 A plug (when the appliance is disconnected!) and examine the wiring and fuse.

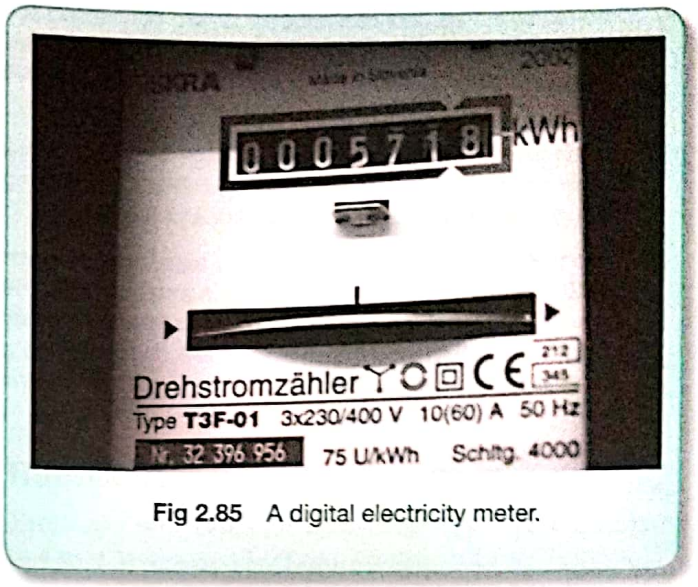


Fig 2.85 A digital electricity meter.

Stabilisers

Stabilisers are used to provide a stabilised voltage in order to protect various household items, including the television and sensitive electronic components, from damage due to sustained abnormal main voltages.

PROJECT

1 *Work in groups* to discuss the basic principles underlying the production of electricity, then design an electric power plant that generates electricity from one of the following sources:
a) hydro, **b**) thermal, **c**) nuclear, **d**) solar, **e**) wind, **f**) tidal or **g**) biogas.

2 Draw your design and label it or construct a small-scale model.

Self check

1 List four sources that drive current through conductors.

2 State Ohm's Law and design an experiment for its verification.

3 Draw an electric circuit with a 9 V battery, three resistors connected in parallel, a switch and the connecting wires.

4 What is the difference between potential difference and electromotive force?

5 Draw a Leclanché cell to show the parts and functions of the parts.

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6 Two resistors, each of resistance 2 Ω, are connected in a circuit with a 6 V battery of negligible internal resistance. Calculate the current flowing in the resistor when they are connected (i) in series (ii) in parallel.

7 An electric tea kettle used at a voltage of 220 V has a power rating of 1.6 k W. Calculate (i) the current flowing through the kettle and (ii) the resistance of the kettle.

8 Two cells with a emf of 1.5 V and an external resistance of 2.0 Ω are connected in series and in parallel. Draw the circuit (both series and parallel) and calculate the current in each arrangement when the cells are connected to a 1Ω external resistor. What will be the new current if the external resistor is replaced with a 2 Ω resistor?

9 A flash light has a 6 V battery and a bulb of resistance 1.4 Ω. What is the value of the current when the flashlight is switched on?

10 List three safety devices associated with an electric circuit. Describe how each functions and the benefits derived from their presence.

11 Compare DC and AC. List the differences between them and the advantages of AC over DC.

12 What are the five effects of electric current in circuits?

13 List six precautions to be taken when using electricity in the home.

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2 Electronics

Learning objective

After studying this unit, you should be able to:

1 connect an amplifier circuit and observe the behaviour of the components.

Background information

We use amplifiers in churches and mosques, on durbar grounds and in entertainment centres. We shall explore amplifier circuits with a view to understanding how this type of circuit works in different gadgets such as microphones, electronic guitars and a few others.

Electronic circuits with appropriate components can amplify low-volume sounds to loud ones, low currents to high currents and low voltages to high ones.

In amplifier circuits a transistor is used to direct the amplification. Resistors always precede transistors in electronic circuits. A resistor is an electronic component that resists the free flow of current. Resistors are measured in Ohms (Ω) and multiples such as kiloOhms (kΩ). Resistors prevent unwanted current from flowing and so prevent destruction of essential components of the devices.

Amplifier circuits

Amplification is applied in radio communication and in musical instruments such as organs and guitars. Knowledge of amplification circuits is significant in appreciating how these circuits operate in some gadgets.

Transistors

There are two types of transistors: N-P-N transistors and P-N-P transistors (Figure 2.86).

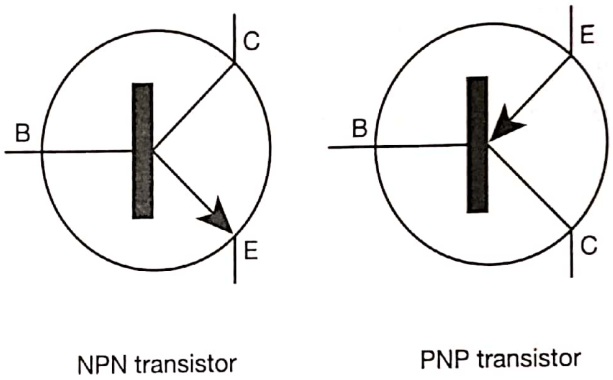


Fig 2.86 Types of transistor

The direction of the arrow (emitter) clearly defines the type of transistor. In N-P-N the arrow directs outside and in P-N-P the arrow moves towards the base. Transistors are either n-p or p-n junction.

In a P-N-P transistor, a small region of N (representing the base) is sandwiched between the emitter and the collector. Similarly in a N-P-N transistor, a small region of P is planted between the emitter and collector.

Transistors in an amplifier circuit are connected so that they accept an amplification input signal and produce an output greater than the input. This can be accomplished in three circuit configurations:

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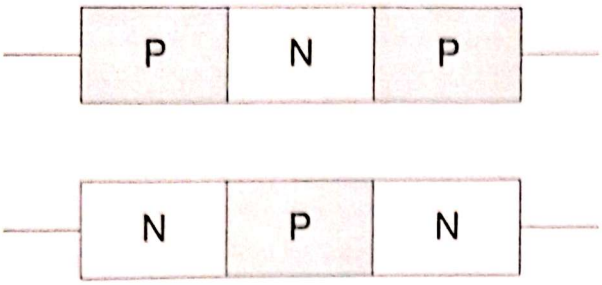


Fig 2.87 Layers in transistors.

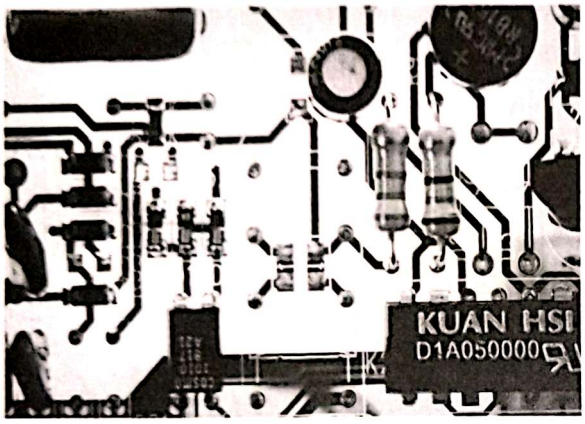
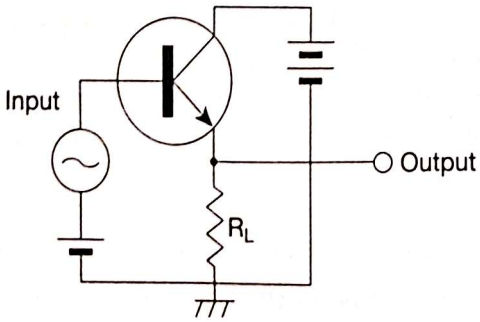


Fig 2.88 Transistors in a circuit.

- common base
- common emitter
- common collector

Each configuration is designed so that it takes a voltage from a power source and uses it to work on a load, such as a resistor in the form of a loudspeaker or earphone. The output voltage across the load is controlled by a small input voltage, from where the microphone is connected.



Common collector circuit
(Emitter follower circuit)

Fig 2.89 Common base circuit.

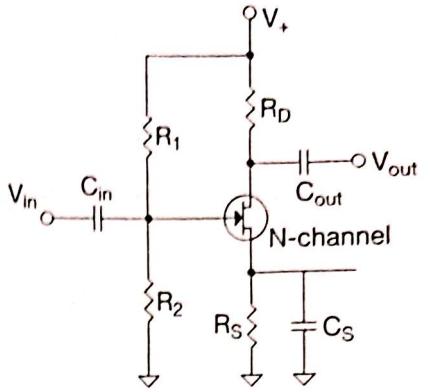


Fig 2.90 Common emitter amplifier.

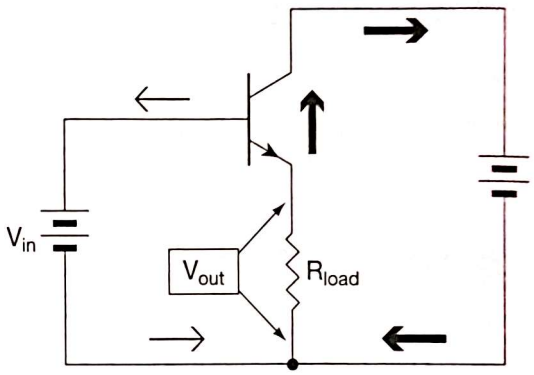


Fig 2.91 Common collector amplifier circuit.

In a common base circuit, the input signal is located between the emitter and the base.

In a common emitter circuit (Figure 2.90), the input signal is between the base and the emitter.

Capacitors

A capacitor is a device for storing electric charges. The stored charge is measured in *microfarads* (μF). A capacitor is made of two conducting sheets ('plates') each containing charges of equal magnitude but opposite (positive and negative) charge. An electric field builds between the two plates. The space between the plates is filled with an insulating material, such as air. This insulating material is referred to as the 'dielectric'.

The capacitance of a parallel plate capacitor is the ratio of the charge in either plate to the potential difference between the plates.

> Capacitance = charge on one plate/p.d. between the plates.

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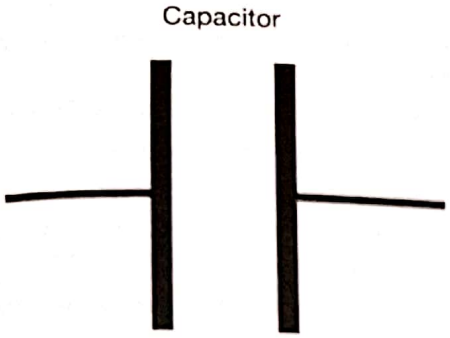


Fig 2.92 Symbol for capacitor.

Capacitors in an electronic device charge and discharge their stored charge to amplify the input signal. There are three types of capacitors:

- paper, plastic, ceramic and mica capacitors
- electrolytic capacitors
- air capacitors.

ACTIVITY 1 Designing and constructing a simple amplifier

Material needed: microphone, 10 μF capacitor (C_1) 10 μF capacitor (C_2), 100 kΩ resistor (R_5), 1 kΩ resistor (R_2), 9 V battery, earphone and a loudspeaker, piece of plywood approximately A4-size, soldering materials, hammer, nails and N-P-N transistor (BC 108).

1 Copy the circuit diagram on to A4 paper

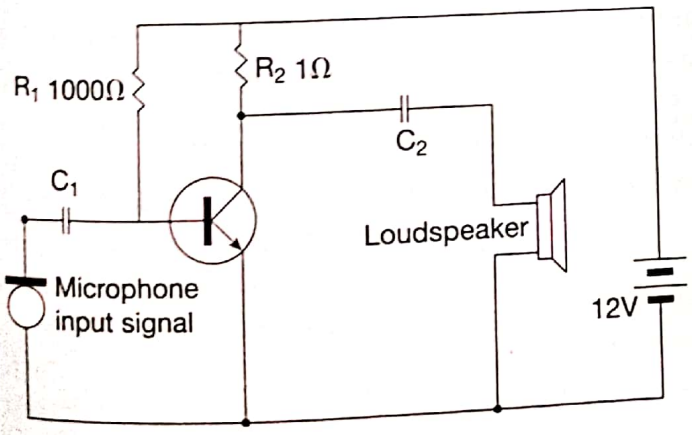


Fig 2.93 Simple amplifier circuit

2 Fix the diagram on the plywood and hammer nails at the points shown

3 Connect the circuit by soldering connecting wires and components

4 Connect the battery to the circuit

5 Switch on the circuit and record the behaviour of the earphone or the loudspeaker

6 What happens if capacitors are removed from the circuit?

7 What feedback do you receive from the circuit?

In this activity, you might have heard a noise coming out of the earpiece. This is called **feedback**. This occurs in DC circuits without capacitors. The capacitor prevents DC from passing through the microphone, upsetting the biasing that allows alternating current to flow.

ACTIVITY 2 Designing and building an amplifier using resistors and three capacitors to improve the output signal in a public address system

Materials: 3 capacitors (C_1 10 μF, C_2 210 μF, C_3 47 μF), resistors 68 kΩ, 15 kΩ, 1 kΩ and 2.2 kΩ, N-P-N transistor, soldering materials, 12 V battery, switch, microphone, earphone, loudspeaker, plywood, nails and hammer.

1 Design and draw the circuit diagram on paper and fix it on the same size of plywood as the paper

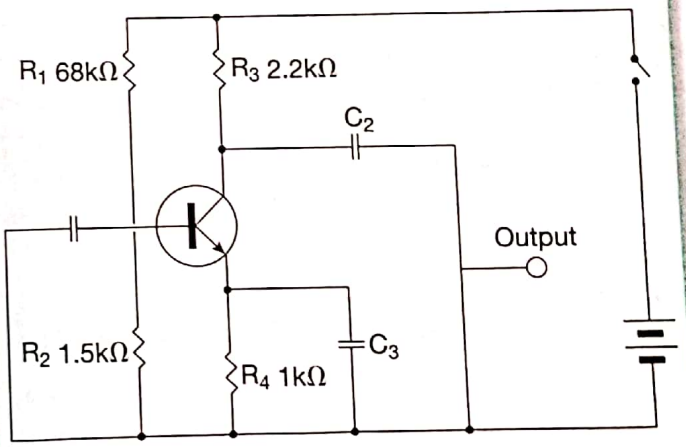


Fig 2.94 Common emitter amplifer

2 Nail the plan on the plywood at the indicated points.

3 Fix the components.

4 Check the circuit.

5 Connect the 12 V battery to the fixed components.

6 Switch on the circuit and speak into the microphone.

7 Compare the circuit with the previous one.

8 Vary the resistances and the capacitors and compare their effect on the quality of the sound (its timbre).

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Project

Design and construct your own simple amplifier for use in a school assembly.

Self check

1 What components are essential in the amplification of a sound signal?

2 Which component precedes a transistor in an electronic circuit? What role does this component play?

3 Draw a P-N-P transistor circuit and show the parts.

4 How is a P-N-P transistor different from an N-P-N transistor? Illustrate the answer with well-labelled diagrams.

5 Draw a basic common base circuit and show the parts.

6 What is a capacitor? What are the roles of capacitors in amplification of signals?

7 State the ratio for finding the capacitance of a capacitor and the appropriate unit for capacitance.

8 List three gadgets that amplify signals and their uses.

9 Draw an electronic circuit to be used to construct a public address system for school assembly.

10 In soldering the components of an electronic circuit, what precautions should be taken?

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3 Sound

Learning objectives

After studying this unit, you should be able to:

1 explain the sources and nature of sound
2 describe musical notes and distinguish musical notes from noise
3 identify the parts of the human ear and describe their function.

Background information

The study of sound is concerned with the variety of sounds that we can hear, how sounds are produced, how the sound reaches our ears and how our ears distinguish one sound from another.

Sources of sound

If you touch your voicebox while singing or humming, you can feel your throat vibrating. If you spread sand on a drum and beat the drum, you will see the particles of sand dancing about on the drum. If you strike a tuning fork and place it by a piece of cork suspended on a string, it knocks the cork away, showing that the prongs of the fork are vibrating.

Sound is produced as a result of an object vibrating. Any object set vibrating produces sound. The vibrations set up waves in the air or in the medium that is in contact with the vibrating object. The vibrating object may be a string, a sheet (or skin), a reed or a column of air. The sound waves set up radiate out in all directions from the source (the point where the vibration occurs) through the medium.

Sources of sound can be classified into three main groups:

- percussions (drums, xylophone, afrikyiwa)
- wind instruments (pipe organ, trumpets, clarinet, flute (atenteben))
- stringed instruments (guitar, violin).

All these instruments produce sound through vibration. **Percussion** instruments (such as a fontonfrom) produce sound when the skin is struck and vibrates the air above. **Wind** instruments (such as a trumpet or atenteben) produce sound when the instrument vibrates and vibrates the air. In **string** instruments (such as a violin) plucking or vibrating the string with the bow vibrates the air around the instrument. The vibrations of the instruments are transmitted through the air in a progressive longitudinal wave.

Any elastic body capable of vibrating can be a source of sound.

ACTIVITY 1 Investigating vibrations

Materials needed: strings, water, bottles, chalk particles, drum and a tuning fork.

1 Explore various ways by which a string can be made to produce sound. You may include traditional string instruments in your exploration
2 Fill eight bottles with water to different depths (Figure 2.95)
3 Blow air into each bottle and record what you hear. Were the sounds the same?
4 Spread the chalk particles on a drum and gently beat the drum. What do you observe about the particles? What does this tell you about how the sound is produced?
5 Strike a turning folk on a solid surface and listen to the sound produced. How is the sound produced?

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Figure 2.95 Eight bottles filled with water to different depths.

The speed of sound

Sound travels at different velocities in different media. The speed of the sound waves depends on the properties of the medium, such as its density and its elasticity. Empty space contains no material (it is a vacuum) and sound will not travel through it.

The speed of sound in air varies with the temperature of the air: sound travels more quickly in warm air than in cold air. People who live near the sea say the waves are louder at dawn than in the afternoon. At dawn, the air near the ground is colder than the air higher up, so the sound above moves more quickly than that near the ground. The sound is refracted (bent) in a curve that goes from the sea and back down on the Earth. In the afternoon, the sound is refracted upwards into the sky, where it is lost.

The speed of sound is greater in solids than in liquids and much greater than in gases. For example, when a train is far away, we can hear the rumblings in the rails even though the train is not yet near enough for us to hear it through the air. We can demonstrate the transfer of sound through solids in the string telephone.

ACTIVITY 2 The string telephone

1 Get two empty cans (such as milk cans) and punch a hole in the bottom of each one. Pass a string about 4 m long from the hole in one can to the hole in the other (Figure 2.96).

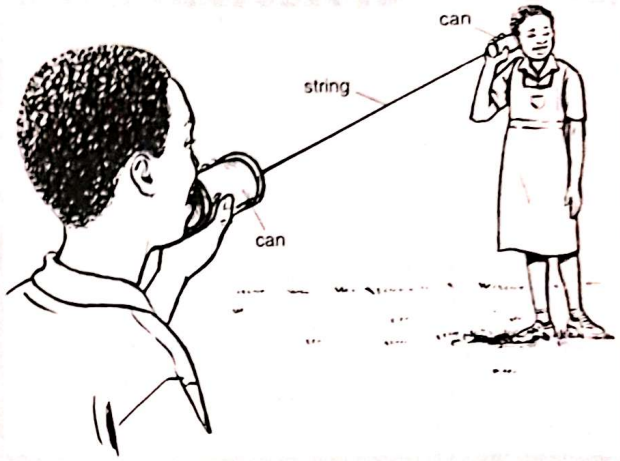


Fig 2.96 The string telephone.

2 Work with a fellow student: hold the string taut between you. Speak into one can while the other student listens in the other can. What happens?

3 What happens if someone touches or holds the string at any point?

The speed of sound in air changes with the direction of the wind and the temperature of the atmosphere. It also changes with the humidity of the air.

Sound travels from the source and takes time to reach the listener. We can see this when we watch a carpenter hammering on a roof, footballers kicking a ball at a distance or a tennis player hitting the ball at a distance. First, we see the impact and then hear the sound some time later.

ACTIVITY 3 Determining the speed of sound in air

1 Two people, one (A) with a toy gun, the other (B) with a stopwatch, stand at least 200 m from each other.

2 Person A fires the toy gun. Person B sees the smoke from the toy gun and starts the stopwatch to time the interval between seeing the smoke and hearing the sound of the shot.

3 Repeat the process three times and calculate an average speed for the sound.

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Activity 4 Investigating the need for a material medium for the transmission of sound

1 Connect a bell jar to a vacuum pump, as in Figure 2.97.

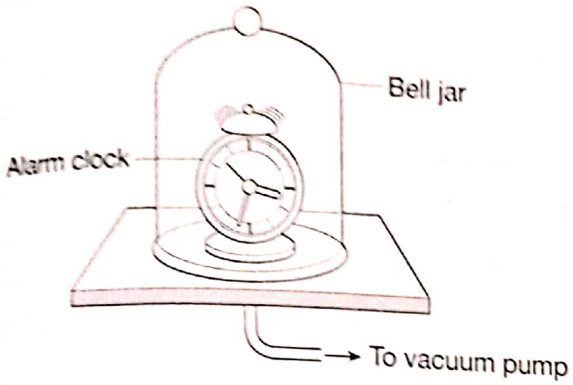


Fig 2.97

2 Switch on the electric bell; record what you hear

3 While the bell is ringing, remove the air from the jar using the vacuum pump

4 Record what happens

5 Explain why there was no sound.

The activity shows that sound cannot be transmitted in a vacuum. Sound needs a material medium for its transmission.

Sound travels at different velocities in different media.

Sir Isaac Newton discovered that the velocity of sound is proportional to the square root of the ratio of the pressure and the density of the medium involved.

$$\text{Velocity of sound} = \sqrt{\text{pressure}/\text{density}}$$

At a constant temperature the pressure : density ratio is constant. Other factors that do not affect the velocity of sound are its pitch, loudness and pressure changes.

The nature of sound

A sound wave is a longitudinal wave

There are two kinds of waves: transverse waves and longitudinal waves.

In **transverse waves**, such as ripples on the surface of water, the vibration moves in a direction perpendicular to the direction of the wave propagated. The wave has crests and troughs (Figure 2.98). (Waves in the electromagnetic spectrum, for example light and radio waves, are transverse. Nothing actually moves or vibrates but the electric and magnetic fields that propagate the waves oscillate at right angles to the direction of travel.)

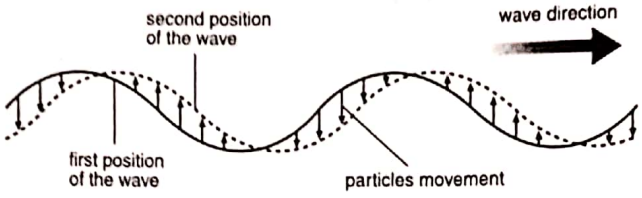


Fig 2.98 Vertical cross-section of a water (transverse) wave.

In **longitudinal waves**, such as sound waves, the vibrating particles move forwards and backwards in the same direction as the wave motion. This produces compressions and rarefactions. Sound waves are longitudinal waves (Figure 2.99).

The **wavelength** of a wave is the distance between any two consecutive crests or troughs or between any two rarefactions or compressions. The **frequency** of the wave is the number of complete waves passing a point each second. This is the same as the number of oscillations made by the source of the wave each second. Frequency is measured in Hertz (Hz); one Hertz equals one oscillation per second.

The **velocity** of a wave is equal to the wavelength multiplied by the frequency. It is measured in metres per second ($m\ s^{-1}$).

The **wave equation**:
Velocity (v) = Wavelength (λ) × Frequency (f)

The velocity of sound in air is 333 $m\ s^{-1}$, in seawater it is 1540 $m\ s^{-1}$ and in brass it is 3650 $m\ s^{-1}$. These values vary slightly, depending on the temperature.

When a wave passes an obstacle or goes through an aperture, it can go round the obstacle or spread out of the aperture, provided the wavelength is of similar size to, or greater than, the aperture. This is called **diffraction** (Figure 2.100). For sound waves, the width or thickness of obstacles (such as trees) and apertures (such as doors and windows) are small compared with the wavelength so, unlike light, sound can go round corners.

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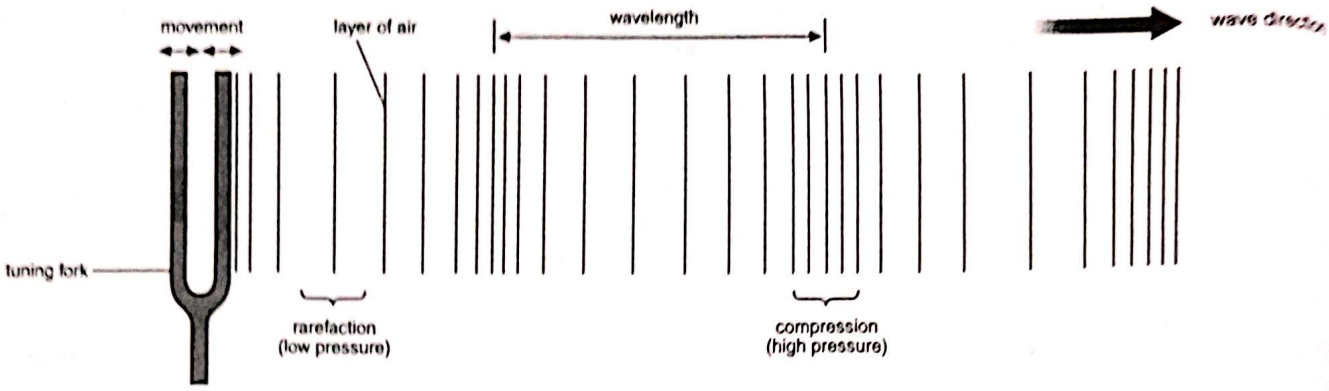


Fig 2.99 Sound waves are longitudinal waves.

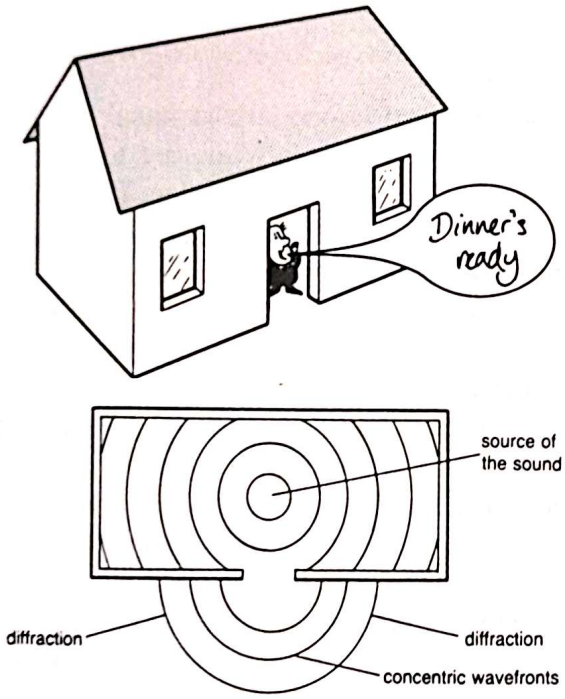


Fig 2.100 Diffraction of sound waves.

Reflection of sound waves

When a sound wave meets a rigid surface it is **reflected**. This reflected wave produces an **echo**. A true echo is a single reflection (or image) of the source of the sound. The reflecting surface may be a wall or the canopy formed by the leaves of forest trees. Echoes can be used to measure the speed of sound.

To create an echo, the reflecting surface must be hard. Telephone booths, for example, have glass panels to reflect sounds outside, so that the caller's voice is clearly heard in the telephone. If the reflecting surface is soft, the sound will be absorbed. If the surface is very uneven, the sound will be reflected in such a diffuse (that is, it bounces off in all directions) manner that we cannot locate the source (the echo). Some halls and rooms deliberately have walls that absorb any sound that falls on them, for example broadcasting and recording studios.

Sailors use **echo sounding** to measure the distance to the ocean bed. Echo sounders send sound waves down through the sea and measure the time the echo takes to come back. Echo sounding is also used in fishing boats; the sound waves reflect back off shoals of fish. Geologists use echo sounding to locate the presence of oil in the Earth's crust. Doctors use **ultrasound** (very high frequency sound waves) to 'see' internal organs and structures in the body, particularly the developing baby in pregnant women. Bats use **echolocation** to navigate through their environment in the dark and to find their food.

Musical notes and noise

The properties of sound

A sound is distinguished by three features:

- pitch
- loudness
- quality (or timbre).

If we identify a sound as being regular in pitch, loudness and timbre, we consider it to be a musical note. If not, then we consider the sound to be noise.

The **pitch** of a sound depends on the frequency (number of vibrations) per second produced by the vibrating source: the higher the frequency, the higher the pitch. If the higher of two musical notes has a frequency twice that of the lower notes, we hear the

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two notes as being an octave apart. Similar ratios of frequencies determine all the other pitches of the diatonic musical scale.

The **loudness** of a sound is based on the energy in the sound wave, which in turn depends on the energy of the vibrating body. For example, a drum that is struck fiercely will produce a louder sound – but of the same pitch – than when it is struck gently. The sound waves from the loud drum have greater **amplitude** than those of the quiet sound. The unit of loudness is the **bel**. This is too large a unit for everyday use, so the intensity of sound is measured in **decibels** (dB). One decibel is a tenth of a bel.

The **quality** (or **timbre**) of a sound depends on the number and combination of harmonics and overtones that it contains. When a musical instrument plays a particular note, the air around it is made to vibrate mainly at one **fundamental frequency**, which gives the pitch of the note. However, the air also vibrates with a range of higher frequencies with much smaller amplitudes. These are called **harmonics** and have frequencies that are multiples of the fundamental frequency.

The harmonics produced by a particular instrument are called its **overtones**; they give its sound characteristics that make it instantly recognisable. The human ear can distinguish more than three thousand harmonics and overtones. The sounds that we hear are considered enriched and pleasant or unpleasant according to the combinations. The mixture of overtones and harmonics from many instruments makes the sound from an orchestra pleasing. However, some combinations produce discordant sounds.

Musical instruments

Musical instruments use various methods to produce sounds. The strings on stringed instruments are plucked, bowed or struck to make them vibrate and produce sound. The pitch of a note is inversely proportional to the length of the string under the same tension.

In wind instruments, a device (such as a reed) vibrates, making the air inside the instrument vibrate in resonance. The air vibrates in many overtones and harmonics depending on factors such as the length of the instrument.

When a percussion instrument, such as the skin or membrane covering a drum, is struck, the skin vibrates, making the air beneath the skin resonate. The pitch of the note depends on the volume of air beneath the instrument.

In pipe instruments, such as church organs, the air in the pipes resonates when the frequency of the vibrating body reaches the natural frequency of the column of air inside the pipe. Different lengths of a tube or pipe resonate to different frequencies (or pitches): the longer the pipe, the lower the pitch.

The sound box of a guitar or a violin resonates to the frequency of the vibrating strings, making weak sounds louder.

The chest, the head, nose and ears all resonate to the frequencies produced by the voicebox in speaking and singing.

ACTIVITY 5 Investigating how the pitch produced by a stringed instrument depends on the length of wire between bridges

1 Take a guitar. Finger a note on one of the strings and pluck it, finger a different note on another string and pluck. Compare the pitches you hear.

2 Repeat step 1 with another string. This time, vary the distance at which you finger the string and record when a high or low pitch is produced.



Fig 2.101 A guitar

ACTIVITY 6 Finding out whether the pitch depends on the tension in the string

1 Load a string on a sonometer with a weight. Pluck the wire and note the pitch.

2 Increase the load; note the tension in the string and the corresponding pitch.

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In this activity, you will notice that the pitch of the note increases with an increase in the tension applied between the ends of the string.

ACTIVITY 7 Exploring whether the pitch depends on the mass per unit length of the string.

1 Use two wires of the same material but different diameter.
2 Fix the wires on a sonometer as shown in Figure 2.102
3 Hang identical weights on each wire.
4 Move the bridge to the same point on each wire, pluck the wire and record the differences in the pitch.
5 Alter the distance of the bridge and note the change in pitch.

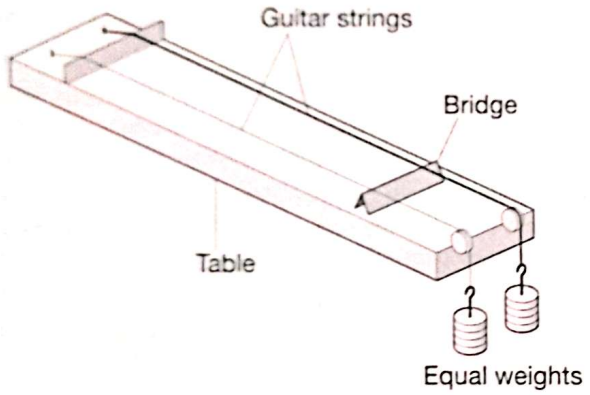


Fig 2.102

In this activity you will see that the frequency decreases if the diameter of the wire or its length is increased, provided the tension and length remain the same.

The Doppler effect

When a vehicle sounding a siren, such as a fire engine or ambulance, goes past us, we notice an apparent change in the pitch of the sound. The pitch is higher when the vehicle is approaching and lower when it is receding. We hear the same effect if we stand on a railway platform when a train goes past. The whistle of the approaching engine sounds high but becomes low when the train has passed.

This apparent change in pitch is called the **Doppler effect.** It occurs because the source of the sound and the observer are moving relative to each other. If they are approaching each other – that is, they are getting closer together – the pitch is high but if they are parting the pitch falls.

The same effect also occurs with light (where the apparent change in frequency causes a colour change) and other waves. It shows us that the stars and other heavenly bodies are moving away from each other as the Universe expands. The effect is known as the **red shift.**

The radar speed detectors used by traffic police for detecting and checking speeding also use the Doppler effect. Bats, which use ultrasound for finding their way and locating their prey use the frequency changes of the Doppler effect to detect the movement of their prey.

The human ear

The ear is made up of three parts: the outer ear, the middle ear and the inner ear (Figure 2.103).

Outer ear

The outer ear consists of the **pinna**, which collects sound waves and directs them down the **ear canal**, where they strike the **ear drum** (the tympanic membrane) and cause it to vibrate. Wax and hairs protect both the canal and the ear drum.

Middle ear

The middle ear is air-filled and contains three small bones (the auditory **ossicles**):

- the hammer (**malleus**)
- the anvil (**incus**)
- the stirrup (**stapes**).

These carry the vibrations across the middle ear and cause the **oval window** to vibrate. They also amplify the vibrations by about twenty times. The **Eustachian tube**, which opens into the throat (the pharynx) equalises the pressures on both sides of the ear drum.

Inner ear

The inner ear is filled with fluid and contains the **cochlea**, which is concerned with hearing and the **semi-circular canals**, which are concerned with balance.

The cochlea is spiral-shaped. It is made up of three tubes: the outer two tubes are filled with **perilymph** and the inner tube with **endolymph.** The cochlea

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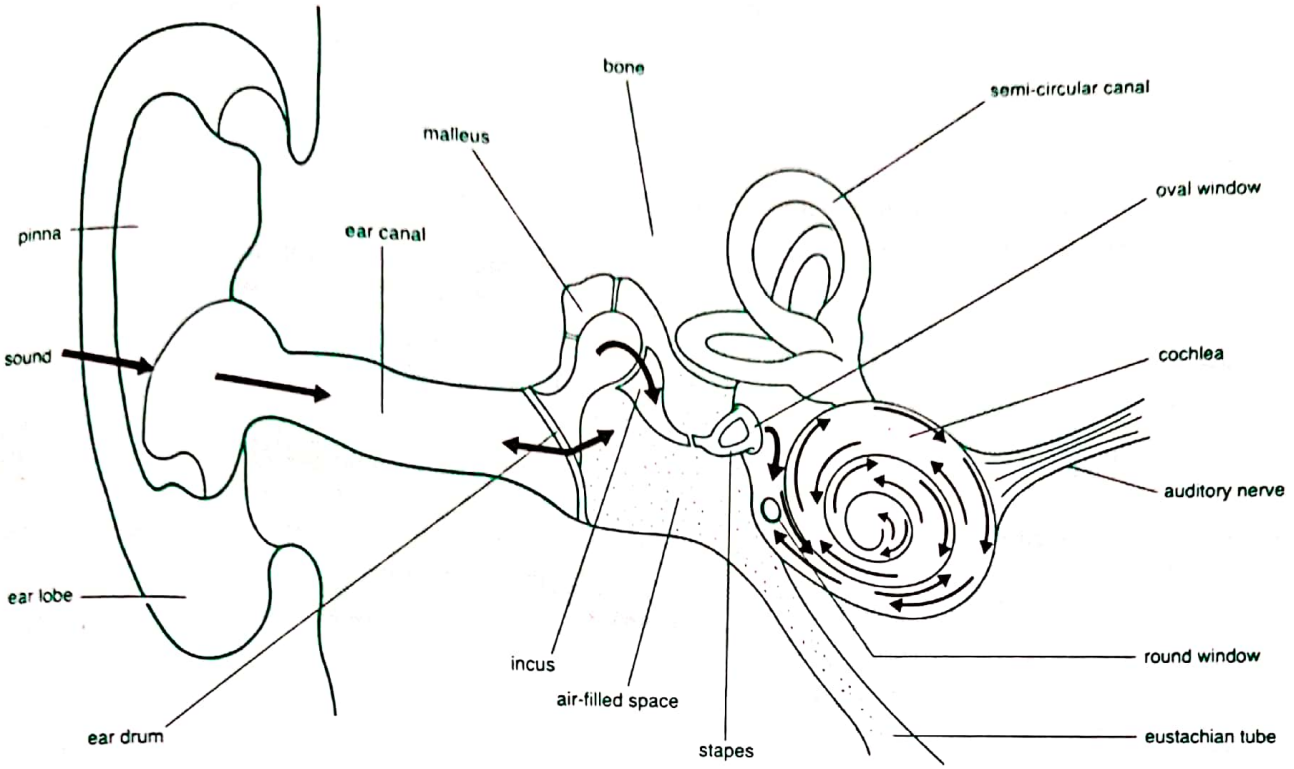


Fig 2.103 The human ear.

is lined with fine hairs, which are vibrated by sound waves. The vibrations activate the auditory nerve, which sends nerve impulses to the brain. The brain interprets the nerve impulses as the sounds we hear. Loud sounds cause permanent damage to the tiny hairs in the cochlea; this can lead to partial deafness over time.

Various parts of the cochlea are thought to respond to different pitches of sound. High-pitched sounds stimulate the cochlea hairs close to the oval window, while low-pitched sounds stimulate hairs further up the spiral. Different animals respond to different frequencies; for example, young humans can detect frequencies up to 20 000 Hz but dogs and bats can distinguish frequencies up to 100000 Hz. Sound above 20 000 Hz is called **ultrasound**.

Sound amplifiers

Several devices amplify quiet sounds to make them audible. Doctors use a stethoscope to amplify the heartbeat. An ear trumpet helps partially-deaf people to hear. The megaphones used by traders to advertise their wares and the microphones used in large auditoria are electronic devices that amplify sound. And of course sounds can be used to modulate radio waves, which are then transmitted round the world by modern broadcasting and communications systems.

Sound reducers

Ear muffs are worn to keep the ear warm in cold weather or to protect the ears from very loud sounds. They are made of small pads of thick cloth joined by a band which goes over the top of the head. Ear muffs reduce the intensity of sound entering the ear because they absorb some of the sound energy so that less energy reaches the middle ear. This protects the timpanic membrane and the ossicles from damaging shocks.

Self check

For questions 1 to 4, choose the letter that refers to the correct option.

1 The frequency of a sound wave is 20 Hz. If it has a wavelength of 0.4m, what is the speed of the wave?

A 50.0 m s^{-1}
B 40.0 m s^{-1}
C 20.0 m s^{-1}
D 8.0 m s^{-1}

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2 Which of these musical instruments produces sound by vibrating a column of air?
- **A** organ pipe
- **B** flute
- **C** guitar
- **D** piano.

3 Link the following musical instruments (A–D) with the method used to produce the sound (I–IV)
- **A** drum
- **B** flute
- **C** violin
- **D** cymbals
- **I** vibrating air column
- **II** vibrating metal
- **III** vibrating skin
- **IV** vibrating string.

4 Link the following characteristics of sound (A–C) with their properties (I–III)
- **A** pitch
- **B** timbre
- **C** loudness
- **I** difference in sound between the same note played on different instruments
- **II** depends on the energy in the wave
- **III** depends on frequency.

5 Why does a tuning fork that is struck sound louder if we place its base on the bottom of an upturned bucket?

6 **a)** What is the frequency of a wave of wavelength 20cm if the speed of sound in air is 333 m s^{-1}?
b) What is the frequency and the wavelength of a note one octave lower than this?

7 The sun produces a tremendous amount of energy as a result of the explosions and violent nuclear reactions that occur in it. How is it that we do not hear these explosions on the Earth?

8 Why is the sound of a train approaching from far away heard when the ear is put on the rail before it can be heard through the air?

9 A student fires a starting pistol while standing 495m away from a large wall. Assuming sound travels at 330 m s^{-1}, how long will it be before the echo returns?

10 A ship uses its sonar system to measure the depth of the water it is sailing in. To do this it sends out a short burst of high-frequency sound and times how long it takes for the echo from the seabed to return. If the echo returns in 0.2 seconds and sound travels through sea water at 1540m s^{-1}, how deep is the water below the ship?

11 What is the frequency of the highest-pitched sound the human ear can hear?

12 Name one property of air that affects the speed at which sound passes through it.

13 What are the two types of wave?

14 **a)** The loudness of sound is measured in _____
b) The difference in quality of sound is due to _____ and _____. The difference in pitch is due to difference in _____.

15 The change in frequency of a wave due to the motion of the source is called the _____ _____.

16 Light waves are _____ waves whereas sound waves are _____ waves.

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1 Magnetism

Learning objectives

After studying this unit, you should be able to:

1 distinguish between magnetic and non-magnetic materials
2 explain magnetic fields
3 outline the processes of magnetisation and demagnetisation.

Background information

Humans use interactions of matter to build useful gadgets, to move machines, to facilitate work and to manage their environment. When interactions of matter are not properly managed, the consequences may include, for example, pollution or the outbreak of deadly diseases.

The relationship between magnetism and electricity has led to the invention of appliances used in industry, communication and many spheres of work.

Magnetic and non-magnetic materials

The **lodestone** was first discovered in ancient China. Lodestones are made from magnetite (black iron ore). A lodestone is permanently magnetised; when it is allowed to rotate freely and come to rest, it aligns itself in a north–south direction, anywhere on the Earth. As long ago as the first millennium BC, sailors used lodestones as compasses, to help them navigate. Around 600 BC, in the ancient region of Magnesia, the Ancient Greeks discovered a type of magnetic rock, called periclase or magnesia. This rock is mainly magnesium carbonate and magnesium oxide but it also contains some magnetite, so it is magnetic. This is where we get the word 'magnetism' from.

Magnetic materials include iron, steel, cobalt and nickel. A substance that can become magnetic (and stay magnetic for some time) is called **ferromagnetic**.

If an object is attracted to a magnet, this does not prove that it is also a magnet. It may only be made of magnetic material. The only true test of whether an object is a magnet is whether it is repelled by one of the poles of a known magnet.

A magnet acts on another magnet placed a distance away from it. This is called **remote action**. The second magnet need not be touching the first magnet.

ACTIVITY 1 Investigating magnetic and non-magnetic substances

1 Collect as many different substances as possible.
2 Predict whether the substance is magnetic or non-magnetic.
3 Test your prediction by moving a magnet close to the substance.
4 Classify the materials into magnetic and non-magnetic.

Table 2.13 Magnetic and non-magnetic substances

Magnetic substances	Non-magnetic substance

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Magnets

Magnets have the following features:

- they have north and south poles
- unlike poles (N-S or S-N) attract
- like poles (N-N or S-S) repel
- a field of magnetic force exists around the magnet
- when freely suspended, the magnet dangles and comes to rest with the magnetic axis pointing north–south (N–S).

ACTIVITY 2 Investigating the magnetic properties of materials

1. Collect together two strong magnets, some large nails, some small nails, some objects made of different metals and some objects made of non-metallic materials.
2. Bring the north pole of one towards the south pole of the other. What happens?
3. Bring two north poles or two south poles together. What happens?
4. Put two nails together. What happens? Bring a magnet near a nail and note what happens.
5. Bring another nail close to the end of the first nail away from the magnet. Is the second nail attracted?
6. Place a line of small nails on the north pole of a magnet. Do the same on the north pole of the other magnet. Bring the end nails together. Is there attraction or repulsion between the end nails?
7. Place a line of small nails on the north pole of a magnet. Do the same on the south pole of the other magnet. What happens when you bring the end nails together?
8. One at a time, bring the metallic objects and non-metallic objects near to one of the magnets. Which objects are attracted?
9. Place a sheet of paper between the magnet and the nails. Does the magnetic effect pass through the paper?
10. Place other materials, such as cloth or a leaf, between the magnet and the nails. Does the magnetic effect pass through these materials?

Like poles of magnets **repel** each other: you need to apply a pushing force to bring them together. **Unlike** poles of magnets **attract**: you need to apply a pulling force to separate them (Figure 2.104).

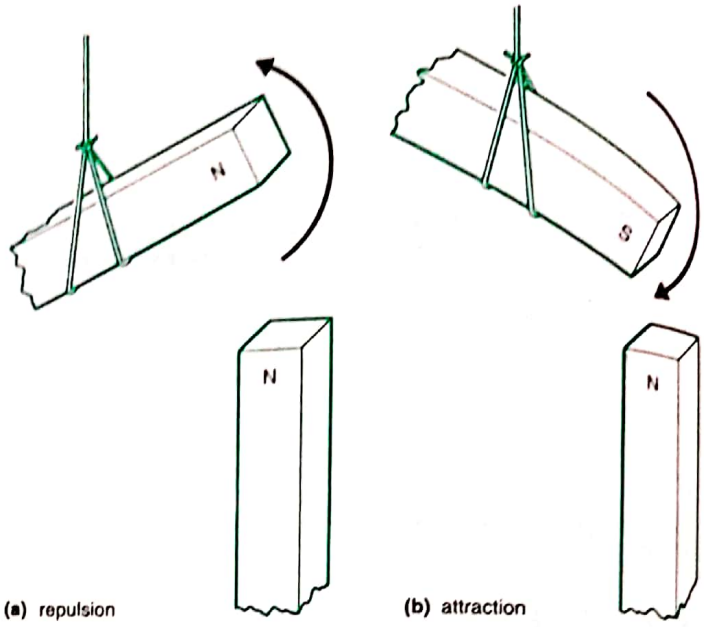


Fig 2.104 Repulsion and attraction: like poles repel, unlike poles attract.

In the laboratory, we can make a magnet by stroking a piece of magnetic material with another magnet. Alternatively, we can pass an electric current through a coil of wire wrapped round the magnetic material.

ACTIVITY 3 Magnetising a magnetic material with another magnet

1. Collect together a large nail or knitting needle, a very strong bar magnet and a plotting compass.
2. Place the nail on a flat surface.
3. Stroke the nail repeatedly in the same direction with the north pole of the magnet (Figure 2.105). Slide the pole along the nail from one end to the other and then lift it away from the nail. Take the pole in a large loop and return it to the starting end of the nail. Repeat this action at least six times.
4. Bring the plotting compass near the needle after stroking. What happens to the compass needle? Explain your answer.

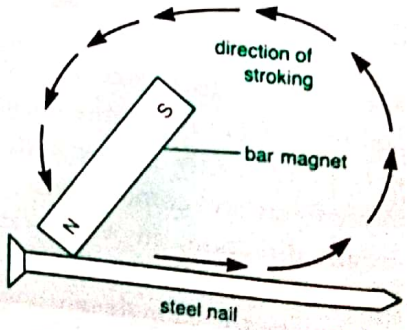


Fig 2.105 Magnetising a nail.

ACTIVITY 4 Magnetising by an electrical method

1 Collect together a large nail or knitting needle, about 2.5m of insulated copper wire, a paper or cardboard tube.

2 Wind the wire on to the tube to form a **solenoid** (Figure 2.106), leaving the ends to be connected to the rest of the electrical circuit.

3 Place the nail or needle to be magnetised in the solenoid.

4 Connect the terminals of the solenoid (with the needle inside) to an accumulator, a rheostat and a key as shown in Figure 2.106 (the teacher will show you how to connect the terminals).

5 Switch on the current with the key for a short time and then switch it off.

6 Take the needle out and use the plotting compass to find the north and south poles. What do you observe?

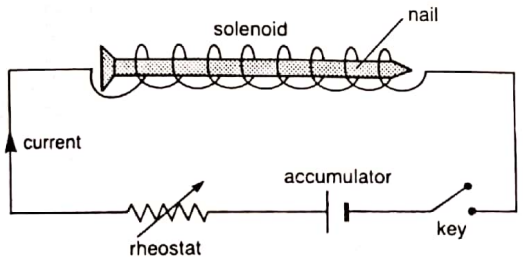


Fig 2.106 Using electricity for magnetising.

Temporary magnets

Objects made of soft iron, such as iron nails, can become temporary magnets when they are attached to magnets. This effect is called **magnetic induction**. The magnetic flux can pass through materials such as paper and cloth. This kind of magnetism is called **temporary magnetism** because the soft iron loses its magnetism when it is removed from the magnet.

Different magnetic substances remain magnetic for different lengths of time. This property is called the substance's **retentivity**. Magnetically 'soft' materials, such as soft iron, have low retentivity; they lose their magnetism quite quickly. Magnetically 'hard' materials, such as steel and some other alloys, have high retentivity; they keep their magnetism for a long time

Materials will lose their magnetism if they are heated to a high temperature or passed through a coil of wire carrying an alternating current. Materials that have lost their magnetism are said to have been **demagnetised**.

Magnets also lose some of their magnetism if they are hammered or knocked about in other ways.

Electromagnets are temporary magnets because as soon as the electric circuit is broken they cease to be magnets.

Permanent magnets

A permanent magnet is one that retains its magnetism for a long time under adverse condition. Steel and other magnets are permanent magnets.

Uses of magnets

Shoemakers or cobblers use magnets to pick up small nails. Electromagnets are used to pick up pieces of iron from mixed scrap metal. Many electrical instruments and appliances contain magnets: microphones, loudspeakers, electric motors and generators. Television sets and oscilloscopes need magnetic fields to direct the beam of electrons that strikes the screen to produce the pictures.

A magnetic compass

A magnetic compass is made from a light magnetic needle fixed to a glass casing. When the compass comes in contact with a magnetic field, the needle settles to lie in a north–south direction. Compasses are used by surveyors, pilots, sailors, boy scouts and girl guides. Compass needles show the direction of magnetic flux in a magnetic field around a magnet.

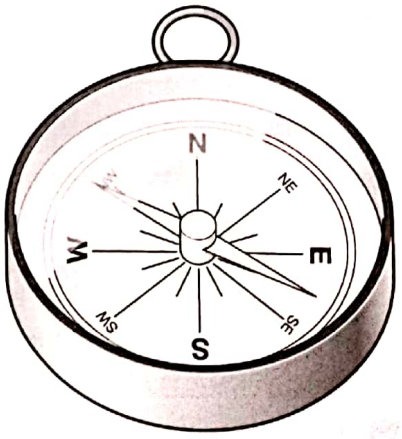


Fig 2.107 A magnetic compass

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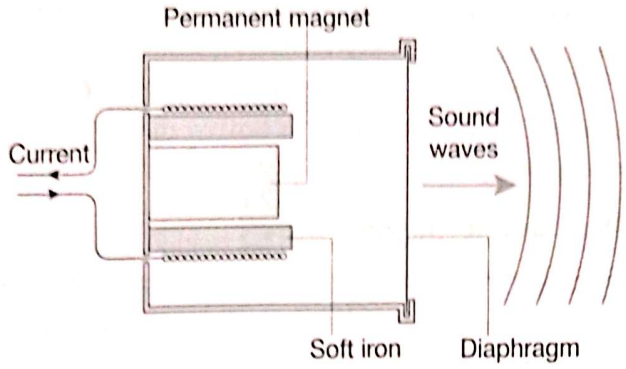


Fig 2.108 Components of a telephone earpiece.

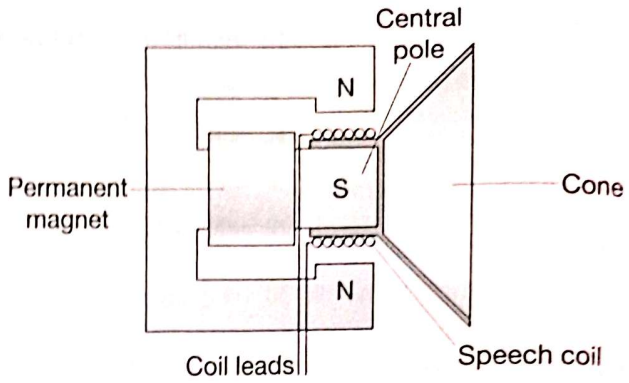


Fig 2.109 Loudspeaker.

Telephone ear piece

When you speak into a telephone, the sound waves produced by speaking hit the small diaphragm in the microphone of the handset and cause it to vibrate. This diaphragm pushes on a layer of carbon granules below, causing their resistance to change and resulting in changes in the electric current in the wires leading away from the handset. The electric signal represents your voice. This kind of signal is called an **analogue** signal. In the 1960s, the telephone network in Ghana was mostly analogue. This is being replaced by digital signals.

At the receiving end, the electrical energy from the telephone wire is converted into sound energy. The varying current from the wire passes through the coil wound round the soft iron cores and magnetises the electromagnet component. The electromagnet pulls the diaphragm towards it. The magnitude of the pull depends on the size of the current. The diaphragm moves to and fro as a result of the varying current and sound waves are produced which are of the same frequency as the incoming signals. This kind of analogue earphone is now being replaced by digital ones.

Loudspeaker

In a loudspeaker, electric current from a record player, radio or television is converted to sound energy. The varying current flows through the coil around the central pole. A force acts on the coil which makes the oscillator oscillate to and fro. A paper or leather cone attached to the coil vibrates the air around the loudspeaker and produces sound.

Microphone

A microphone converts sound energy into electrical energy by changing the pressure variations of sound waves into alternating current.

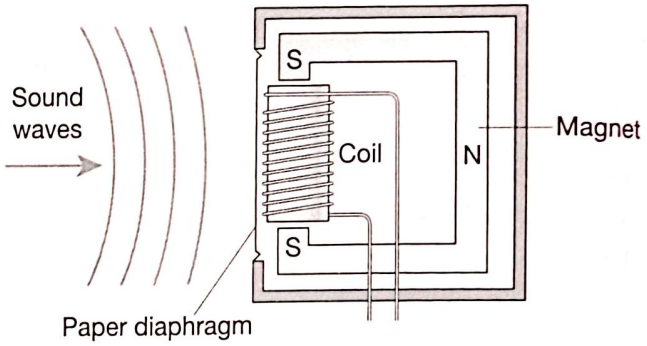


Fig 2.110 Microphone.

In a moving coil microphone, the diaphragm – a paper cone – vibrates as sound waves hit it. As the diaphragm vibrates, a coil of thin wire at its neck moves backwards and forwards in the field of a permanent magnet. The movement in the magnetic field induces AC in the coil.

Generation of electricity

Magnets play a major role in the generation of electricity. Whenever there is a relative motion between a coil and a magnet, an electromotive force is generated which causes electrons to flow. This is **electromagnetic induction**. In a hydro-electricity plant, such as the one Akosombo, a coil is made to rotate in the magnetic field of a huge magnet and causes an electromotive force to move billions of electron along a conductor.

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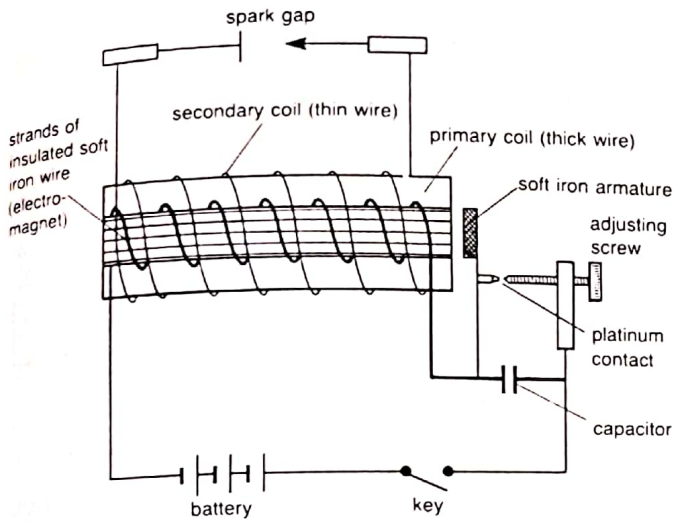
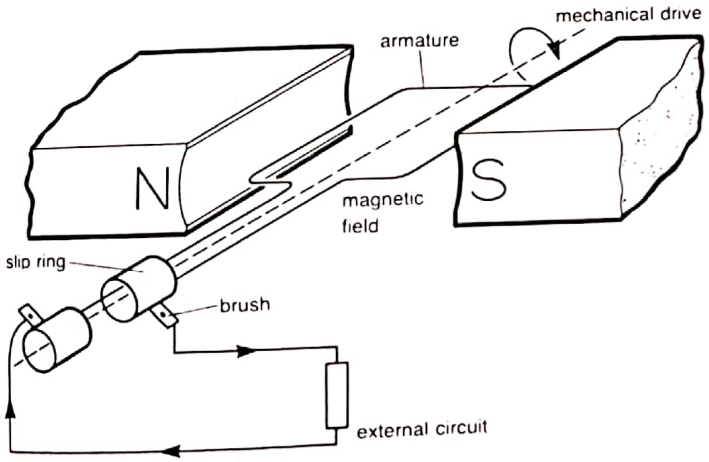
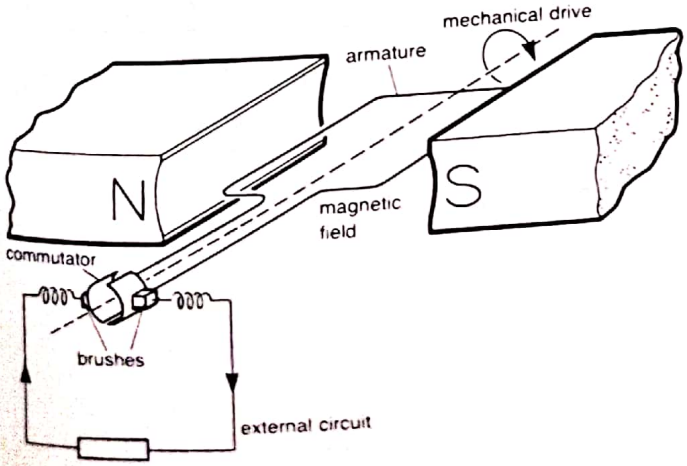


Fig 2.111 An electromagnetic induction coil.



(a) an alternating current generator (alternator)



(b) a direct current generator (alternator)

Fig 2.112 Generators.

Meters

Magnets are used in electrical measuring instruments such as ammeters and voltmeters. In moving coil meters, current flows round a coil pivoted in a magnetic field. This creates a permanent magnet. A force acts on the current-carrying coil and causes it to rotate. A pointer is attached to the coil. The deflection of the pointer tells the magnitude of the current flowing through the coil and serves as a meter.

Fridge door/freezer doors

The doors of fridges and freezers are fitted with magnetic strips and strips of opposite polarity are fixed to the body of the fridge. The attraction between the unlike poles keeps the door closed. If the fridge is made of steel, a magnet attached to the door will be attracted to the body.

Tapes and floppy discs

Audiotapes and video tapes are made of plastic with a thin coating of magnetic material. Each centimetre of tape contains an enormous number of these magnetic particles. As the tape is recording, changes in the electric current alters the alignment of the magnets. When the tape is played back, the changes in the magnetic field are picked up and converted into an electrical signal. Computer floppy discs are thin plastic sheets coated in magnetic material.

ACTIVITY 5 Discussing the uses of magnets

List different uses of magnets and magnetic fields and discuss the importance of magnets in converting electricity to mechanical energy in electric motors, thus producing motion from the flow of electric currents.

Magnetic fields

The region in which the magnetic effect of the magnet can be experienced, or shown to exist, is called its **magnetic field**. Another magnet or a charged particle in a magnetic field will react with the field. To show the influence of the magnet, the magnetic field can be mapped out as magnetic **lines of force**. Lines of force do not truly exist but they help us to imagine the size and shape of magnetic fields.

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We can define a line of force as a line along which a free north pole will move.

A line of force can be thought of as coming out of the north pole of a magnet and going in at the south pole. It continues within the magnet from the south pole back to the north pole. In a solenoid, the lines of force come out of one end of the coil and return at the other end, in a similar way to a bar magnet.

The pole of a magnet or solenoid is the region where the lines of force are closest together.

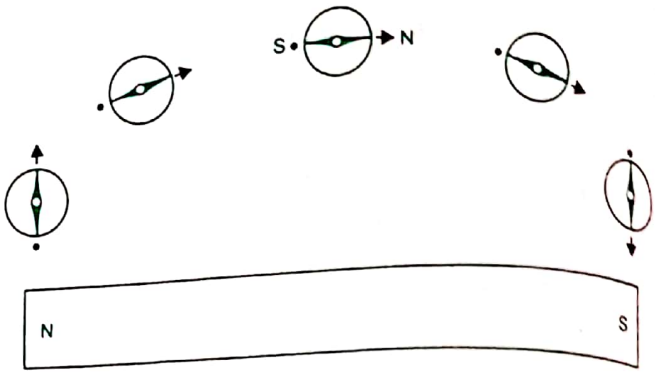


Fig 2.114 Finding the lines of force with a plotting compass.

ACTIVITY 6 Mapping out lines of force around a magnet

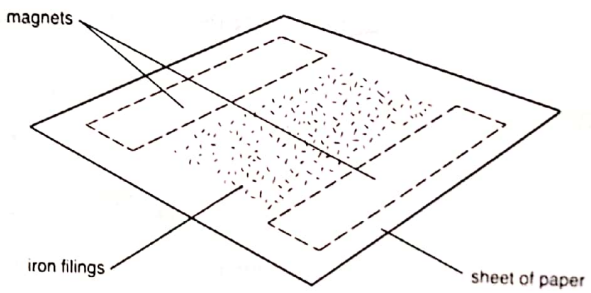


Fig 2.113 Finding the lines of force between two magnets.

1. Collect together two bar magnets, some iron filings and some plotting compasses.
2. Place one magnet on the table and spread a sheet of paper over it to cover it and the area beyond.
3. Sprinkle some iron filings on the paper above the magnet and tap the paper. What pattern do the iron filings make on the paper? Sketch the pattern.
4. Place two magnets with their like poles about 2 cm apart under the paper. Sprinkle iron filings on the sheet of paper (Figure 2.113), tap the paper and sketch the pattern produced.
5. Repeat this with the unlike poles of the magnets about 2cm apart.
6. Repeat this with the magnets parallel to each other.
7. Repeat using plotting compasses instead of iron filings. Put the magnet on top of the sheet of paper and place compasses all around it. For each compass position, mark the 'north' end of the needle with a small arrow and the 'south' end with a dot (Figure 2.114).
8. Remove the plotting compasses and join up the arrows and dots with smooth lines. Your diagram should show the shape and the direction of the magnetic field lines around a bar magnet. The direction of the field is from the dot towards the arrow.

The diagrams you have drawn in Activity 6 should show that:

- A magnetic line of force comes out of the north pole of a magnet and goes in at the south pole.
- Magnetic lines of force do not cross each other.
- A magnetic field is the region within which a magnetic force can be experienced.
- Magnetic lines of force can pass through non-magnetic materials such as paper.

The **neutral point** is one at which two magnetic forces are equal and opposite. The resultant field at this point is zero and no lines of force pass through it. Figure 2.115 shows the magnetic field produced when two north poles are placed close together. Note the neutral point.

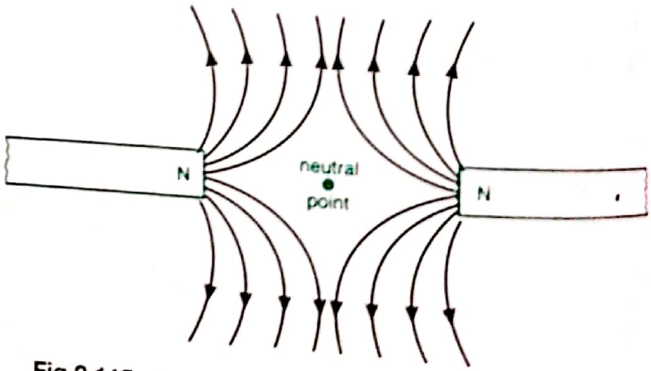


Fig 2.115 The lines of force between two like poles.

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ACTIVITY 7 Mapping the lines of force around a current-carrying wire

1 Collect together a long wire, a battery, a piece of card with a hole in the middle and some plotting compasses.

2 Put the wire through the hole in the card. Hold the card flat and surround the wire with plotting compasses. Connect the wire to the battery so that a current flows through it (Figure 2.116).

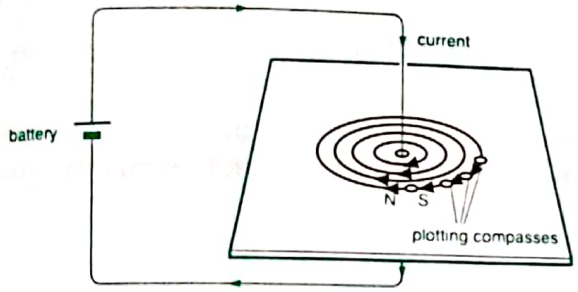


Fig 2.116 Lines of force around a current-carrying wire.

3 For each compass position, mark 'north' with a small arrow and 'south' with a dot. Disconnect the wire from the battery so that the current stops flowing. What happens to the positions of the compass needles?

4 Remove the plotting compasses and join up the arrows and dots with smooth lines. Your diagram should show the shape and the direction of the magnetic field lines around a current-carrying wire.

5 Reverse the direction in which the current flows through the wire by connecting the two ends of the wire to the opposite ends of the battery. Repeat step 3. How does the direction of the magnetic field around a current-carrying wire depend on the direction in which the current flows through the wire?

6 Take the wire and wind it into a coil around your pencil. Remove the pencil and place the coil on a sheet of paper. Place plotting compasses around the coil. Connect the ends of the wire to the battery. For each compass position, mark 'north' with a small arrow and 'south' with a dot (Figure 2.117).

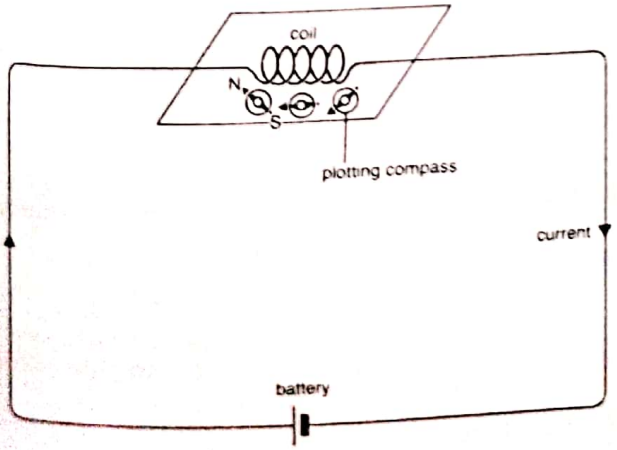


Fig 2.117 Plotting lines of force around a coil of wire.

7 Remove the plotting compasses and join up the arrows and dots with smooth lines. Your diagram should show the shape and the direction of the magnetic field lines around a current-carrying coil of wire.

8 Reverse the direction in which the current flows through the coil by connecting the two ends of the wire to the opposite ends of the battery. Repeat step 5. How does the direction of the magnetic field around a current-carrying coil of wire depend on the direction in which the current flows through the wire?

9 How does the magnetic field around a current-carrying coil of wire compare with the magnetic field around a bar magnet?

Activity 7 demonstrates that a magnetic field exists around a conductor only when it is carrying an electric current. A magnet produced by the flow of electric current through a bar of soft iron in a solenoid is called an **electromagnet**. The direction of the field lines depends on the direction in which the current flows through the conductor. Electromagnetism is sometimes called temporary magnetism because it exists only when an electric current flows.

ACTIVITY 9 Making an electromagnet

1 Collect together a long wire, a battery, a piece of iron, such as a large iron nail, some plotting compasses and some small pieces of magnetic material, such as paper clips or small nails.

2 Wrap the wire round the piece of iron as many times as possible. You must keep wrapping in the same direction. You need at least 30 coils for it to be effective.

3 Connect the two ends of the wire to a suitable battery and while the current is flowing test the piece of iron to see if it is a magnet. What happens when the battery is disconnected? (**Warning:** Do not leave the battery connected in the circuit when you are not using it as the battery will go flat quite quickly.)

4 Can you find out which end of the electromagnet is a north pole? How would you magnetise the iron the other way round? (There are two ways of doing this.) Try your ideas and see if they work.

5 How do you think you could make the magnetism stronger? Again, try your ideas if possible.

The Earth as a magnet

When a freely-pivoted magnetic needle, such as that found in a compass, settles, it does so with one end

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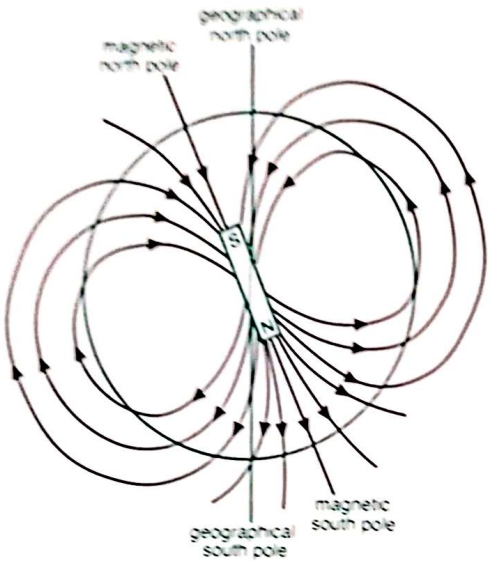


Fig 2.118 The Earth as a magnet.

pointing to the magnetic north and the other end pointing to the magnetic south. The end pointing north is called the **north-seeking pole** or the north pole and the other is called the **south-seeking pole** or the south pole.

The Earth acts as if it has a huge magnet inside it (Figure 2.118). The Earth's north magnetic pole attracts the north pole of a compass needle, therefore it must actually be magnetic south. Similarly, the south magnetic pole is actually magnetic north.

The interior of the Earth, under its crust, is thought to consist of an inner core of solid iron and nickel, about 2600 km in diameter, an outer core of molten iron and nickel, about 2250 km thick and a mantle of mostly solid rock, about 2900 km thick. Iron and nickel are both magnetic materials and this explains why the Earth behaves like a magnet.

The Earth's north and south magnetic poles are not in exactly the same place as the true North and South Poles. Their positions are slowly but continually changing. By 2140, the Earth's magnetic poles will coincide with the true poles. The polarity of the magnetic poles has not always been as it is today. It has reversed many times during the evolution of the Earth.

Magnetisation

Magnetising a demagnetised magnet

A demagnetised magnet can be treated to regain its magnetic properties. This can be done by:

- Stroking a bar of steel with a magnet.
- Placing the steel bar inside a current carrying solenoid of insulated wire
- Induction.

An unmagnetised magnetic material can be magnetised by the **single touch method** to produce poles (N-S) at its ends.

ACTIVITY 9 Magnetising a magnetic material by the single touch method

1 Place a fairly long steel bar on a slab
2 Stroke the bar repeatedly in the same direction with the north pole of a very strong bar magnet
3 Use a compass to test after stroking
4 What do you observe about the compass needle when drawn closer to the steel bar?

When an unmagnetised magnetic material is magnetised by the **double touch method** consequent poles are produced in the middle. (Figure 2.119).

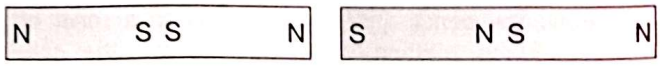


Fig 2.119 Consequent poles produced from double touch method.

ACTIVITY 10 Magnetising a magnetic material by the double touch method

1 Place a demagnetised steel bar on a slab
2 Stroke the steel bar from the centre to the end with the north pole and from the centre to the other end with the south pole of a strong bar magnet
3 Use a compass to test the steel bar

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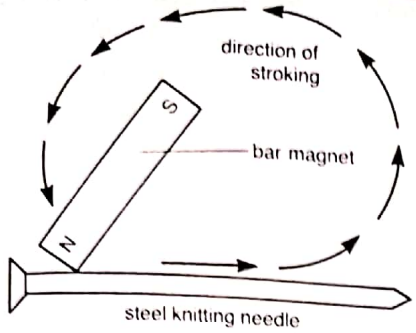


Fig 2.120 Magnetising a demagnetised material.

ACTIVITY 11 Magnetising a demagnetised magnetic material by the electrical method

1 Prepare a solenoid with an insulted copper wire and connect the ends to the anode and cathode of a car battery

2 Place the demagnetised material into the solenoid

3 Switch on or close the circuit of the circuit with the switch

4 Withdraw the magnetic material and test with a compass or a bar magnet

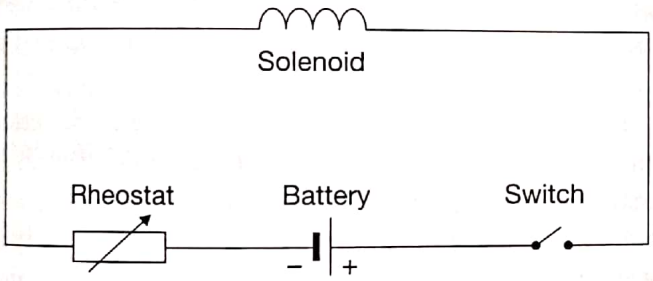


Fig 2.121 Magnetising by the electrical method

Self check

1 Give brief details of how you would turn an iron nail into a magnet using:
   a) another magnet
   b) wire and a battery.

2 Explain the difference between 'magnetic north' and 'true north' poles. Explain how early seafarers were able to navigate using the Earth's magnetism.

3 Describe how you would magnetise a bar of steel so that two north poles appear at the ends.

4 A long wire is to be coiled on a nail so that no magnetism appears in the nail when a current is passed through. Sketch how the wire should be wound to produce this effect.

5 Two north poles of two magnets are placed 3cm apart on a sheet of paper. Draw lines of force from the poles.

6 Two bar magnets are placed horizontally with the south pole of one magnet opposite the north pole of the other. Draw the magnetic flux around them and explain the patterns drawn.

7 Why are compasses essential gadgets for tourist and sailors?

8 With a well-labelled diagram, explain how a steel bar is magnetised by the double touch method.

9 Why does rough handling of a magnetic material cause it to be demagnetised?

10 List materials that are magnetic and explain why some materials are classified as non-magnetic.

11 List the uses of magnets in the following fields of work.
   a) carpentry
   b) medical field
   c) construction of an electric motor

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2 Force and motion

Learning objectives

After studying this unit, you should be able to:

1 define force and outline various types
2 state Archimedes' Principle and the law of flotation
3 explain the terms distance, displacement, speed, velocity, acceleration and momentum
4 explain types of motion and the Newton's laws of motion
5 define centre of gravity and distinguish between stable, unstable and neutral equilibrium
6 explain moment of force
7 define pressure and describe the effects and application of pressure in solids, liquids and gases.

Background information

A force is an interaction of matter; it may or may not involve contact. Forces produce many effects, including motion.

Forces

A force is a **push** or a **pull**. Forces are measured in Newtons (N), using a forcemeter or Newtonmeter. Forces are **vector** quantities, which means they have a magnitude (size) and a direction. When two or more forces act at one point, there is a single resultant force – which may be zero, if the forces are balanced and cancel each other out. The result of two forces acting on a body can be found from an accurate geometric

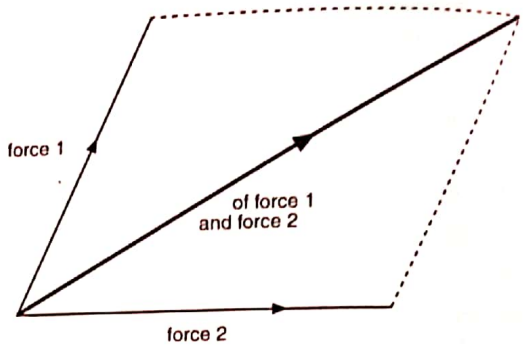


Fig 2.112 The resultant of two forces.

diagram. If the forces are drawn from the point as two sides of a parallelogram, the resultant is the diagonal of the parallelogram (Figure 2.112).

If equal forces are parallel and opposite in direction but not balanced, they form a **couple**, which results in rotation about a point (Figure 2.113).

An unbalanced or resultant force will cause a body to be accelerated. The acceleration produced is proportional to the force applied. This will have the effect of making the body change either speed or direction or both.

Forces in liquids

When a solid moves through a liquid, the liquid particles tend to stick to the surface of the solid and slow it down. This resistance to movement is called **drag** or **viscous drag**. It also occurs when one liquid

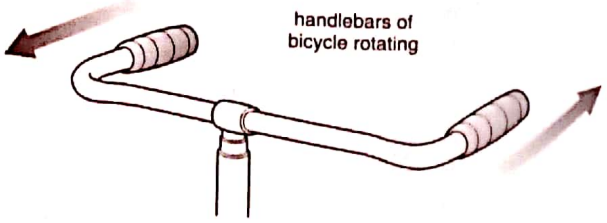


Fig 2.113 A couple.

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flows on the surface of another. Thick liquids, such as syrup, have a high viscosity and so produce a large drag force when you try to move an object through them.

Forces in gases

Gas particles offer some resistance to the movement of solids. When the gas is air, we call this effect **air resistance**. As a raindrop falls from the sky, the air resistance increases until it equals the weight of the raindrop. At this point the resultant force on the rain drop is zero, so it stops accelerating and its velocity does not increase any more but remains constant; the drop has reached its **terminal velocity**. In the same way, a parachutist – or any other body falling from the sky – will reach terminal velocity provided the fall starts sufficiently high above the ground.

Air resistance is the force of friction (see below) between the air and falling objects. If the objects are travelling at high speeds, the results can be spectacular. For example, when meteors and other particles from space enter the atmosphere, air resistance makes them red-hot, or even white-hot, so that they burn up, producing what we call **shooting stars**. Spacecraft that travel back to Earth from space are covered with special heat-resistant ceramic material to protect them from this sort of thermal damage.

Gravitational force

Gravitational attraction exists between any two bodies. The greater the mass of the body, the larger its gravitational attraction. The Sun is the most massive body in the planetary system and therefore attracts all the other planets to it. Similarly, the Earth exerts more attractive force than the moon. All bodies that exist on the Earth are have less mass than the Earth. The Earth as a result, attracts all bodies on it to its centre. Have you considered why objects thrown up tend to fall down?

Weight

The weight of a body is the force with which the body rests on a support. Such a force is determined by the mass of the body and the gravitational force attracting the body towards the centre of the Earth.

Electrostatic force

When a plastic comb is run through the hair many times, the comb becomes electrically charged and the charged comb can attract small objects, such as pieces of paper. When two clouds of different temperatures meet in the atmosphere the frictional force of their interaction produces an electrostatic force, which releases electrons that flow as lightning. Such flows of electrons can set building and coconut trees on fire. Plastic materials become charged when rubbed with fur. A plastic pen vigorously rubbed with wool produces an electrostatic force which can attract particles of dust.

A charged body is surrounded by a region where the force is exerted on another material.

Magnetic force

Opposite poles attract and like poles repel. Magnets are surrounded by magnetic force fields that attract magnetic materials such as iron, steel, nickel and cobalt. A magnetic field of force is created around a current-carrying conductor. An electromagnetic force is produced when a current flows through a coil. Such a force can attract metallic substances.

Friction

All surfaces, even those that look or feel smooth, have some degree of roughness. This is due to minute protuberances on their surface. When two surfaces touch, these protuberances interlock and resist the movement of the surfaces over each other. This resistance is called the **frictional force** or friction. Surfaces that are more deeply embedded in each other show a greater degree of resistance. Friction is proportional to the normal (that is, perpendicular) reaction force between the surfaces.

Friction exists only when surfaces in motion rub against each other. Friction is greatest at the start of motion; this is **static friction**. Once the surfaces have started moving, they do not interlock so deeply and so less friction has to be overcome to keep them moving. This is **dynamic friction**.

Activity 3 in Year 4, Section 55, Unit 1 looks at static and dynamic friction and at ways of reducing friction.

Co-efficients of friction

The co-efficient of static friction is indicated by the symbol μ. Dynamic friction is shown by the symbol μ'. Mathematically, the co-efficients of static and dynamic frictions are expressed as follows:

$$\text{Co-efficient of static friction } (\mu) = \frac{\text{Limiting frictional force } (F)}{\text{Normal force } (R)}$$

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Co-efficient of dynamic friction (μ') =

$$\frac{\text{Limiting frictional force } (F')}{\text{Normal force between surfaces } (R)}$$

Note that the surfaces that have relative motion have frictional force that is directly proportional to the normal reaction and independent of the relative velocity of the surfaces in contact.

Viscosity

This is the frictional force posed by a fluid (liquid or gas) on a body that is moving through it. Oils that resists the movement of bodies within them are good **lubricants**. The adhesive forces between the molecules of the oil offer low resistance to the bodies moving through it and allow the surfaces to move freely. Lubricants reduce the damaging effect of friction to the surfaces of bodies that slide over each other. *Greese* and *Gluceline* are examples of lubricants.

Upthrust

Upthrust is the force with which a fluid resists a body entering it. The upthrust of a liquid is equal to the weight of the object entering it and therefore equal to the amount of fluid displaced by the body, as shown in Archimedes' principle.

Archimedes' principle

When a body is submerged in a fluid (liquid or gas), either partially or fully, the body displaces a quantity of the fluid equal to the volume of the body that is submerged. The body receives an upthrust that tends to push it up out of the fluid. The force of the upthrust is equal to the weight of fluid displaced. Thus, there are two opposing forces acting on the body: its weight, which acts downwards and the upthrust, which acts upwards. The magnitude of these forces determines whether the body will float or sink in the fluid. If the weight of the body is greater than the upthrust the body will sink. However, if the upthrust is greater than, or equal to, the weight of the body then it will float.

ACTIVITY 1 Investigating floating and sinking

1 Collect together a bowl with fresh water and various objects to place in the water, such as a spoon, a brick, a piece of wood, a candle, a fresh egg and a block of plastic.
2 Place each object in the water in turn.
3 Describe what happens or draw a diagram for each object.
4 Explain why some of the objects sink while others float.
5 If possible put the fresh egg in a concentrated salt solution. Write down and explain what happens.

The principle of flotation

A floating body sinks into a fluid (liquid or gas) until it displaces its own weight of fluid. This is why the size of a ship is often given in terms of its **displacement**. The displacement is in units that can be related to weight, such as tonnes. The shape of a ship is such as to allow it to displace a large volume of seawater and thereby receive a large upthrust.

The greater the weight of the floating body the greater the volume of fluid displaced and so the deeper it sinks. A fully-laden ship sits much lower in the water than an empty one.

The Plimsoll line marked on a sea-going ship (Figure 2.124) shows the safe depth to which the ship should be loaded in seas of various temperatures and densities. A ship loaded to a certain level in cold seas will sink deeper in the tropics, because the water is warmer and therefore less dense, so levels are marked that are safe in both cold and warm seas.

A submarine goes beneath the surface of the sea. It has ballast tanks into which water is pumped to increase the average density of the submarine and make it sink. To bring it back to the surface air is pumped into the ballast tanks. This displaces the water and decreases the average density of the submarine.

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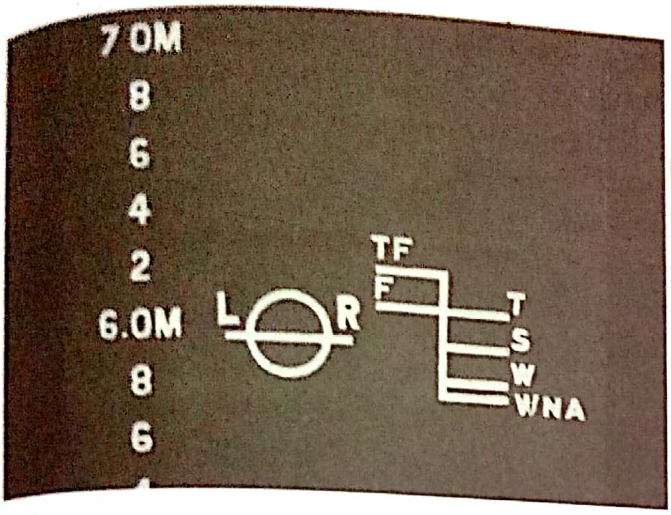


Fig 2.124 The Plimsoll line on a ship.

Flight

Aeroplane wings and bodies are shaped in such a way that the air is forced to split and flow under and over the wing. The sudden change in velocity and direction of the airflow causes an area of low pressure to form on the upper surface of the wing. The air flowing underneath the wing is forced to move more slowly, causing an area of high pressure underneath the wing. The resultant of these two changes of force produces lift on the aeroplane's wing.

The fundamentals of bird flight are very similar to mechanical flight. The shape of the bird's wing as it moves through the air causes an area of lower pressure above the wing and an area of higher pressure beneath the wing.

Both aeroplanes and birds have streamlined bodies (a smooth, even, shape that offers the lowest possible air resistance) which makes it easier for them to fly through air masses.

ACTIVITY 2 Investigating how aeroplanes fly

1. Hold a strip of paper horizontal to your mouth.
2. Blow air continuously over the paper from your mouth and observe what happens.
3. Explain what you observed in terms of the flow of air over and under the strip of paper.
4. Use the experience from the activity to explain how birds and aeroplanes fly.

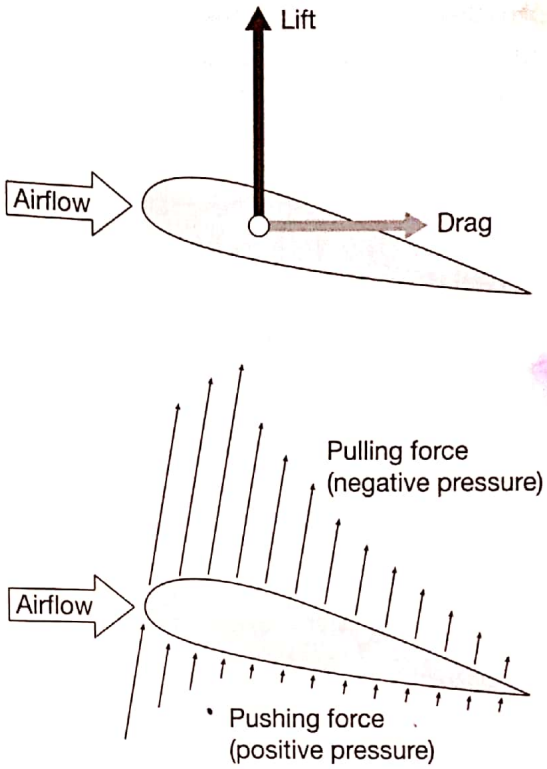


Fig 2.125 Forces acting on a wing in flight

Distance, displacement, speed, velocity, acceleration and momentum

Motion

Whenever a force overcomes the inertia of a body at rest the object moves in the direction of the force.

Distance

Distance is the interval between any two points. It is a **scalar** quantity (it is defined only by its magnitude).

Distance is measured in metres or its multiples, such as kilometres, or its submultiples, such as centimetres and millimetres.

Displacement

Displacement is the distance covered by a moving body in the direction of the force or forces moving it. It is a **vector** quantity (it has both a magnitude and a direction).

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Displacement is represented with a line (drawn to scale) for the speed and an arrow showing the direction of movement.

Speed

Speed is the distance covered between any two points in a specific time. Speed is a scalar quantity; its unit is ms^{-1}. Speed is the rate of change of distance with time.

Speed (s) = distance (m) / time (t).

Velocity

Velocity is the displacement (s) between two points in a specified time (t). Velocity is a vector quantity; its unit is ms^{-1}. Velocity is the rate of change of displacement with time.

Velocity (v) = displacement (s) / time taken (t).

Acceleration

Acceleration is the change of velocity with time.

When a body or a system changes its velocity uniformly in a specified time (t), the velocity at the beginning of the motion is the initial velocity u and the final velocity is denoted v.

Average velocity $= (u + v)/2$
Acceleration is (a) $= ((u + v)t)/2$.

When a body's velocity increases or decreases, its direction may change or may remain the same. When there is a rate of change of velocity in a specified time, the body is said to be accelerating. Acceleration can denote either an increase or decrease in velocity.

Acceleration is a vector quantity with magnitude and direction.

Acceleration = (final velocity – initial velocity) / time taken.

$a = (v - u)/t$

$v = u + at$

If the body moves with uniform motion then, the distance covered is expressed as

$s = ((v + u)/2) \times t$

Substituting the equation for velocity ($v = u + at$):

$s = ((u + at + u)/2) \times t$.

$s = ((2u + at)/2) \times t$.

Momentum

When a body is in motion, it gathers **momentum**. The momentum gathered depends on two factors: (i) the mass of the body in motion and (ii) the velocity with which the body moves.

Momentum (P) is the product of the mass of the body and its velocity

$P = mv$

where m is the mass and v is its velocity.

Whenever a bigger body and a smaller body are acted upon by the same magnitude of force their moment remains constant. However the smaller object builds up a higher velocity.

The relationship between force and momentum was explained by Sir Isaac Newton in his second law of motion.

Newton's laws of motion

Newton's first law of motion

In 1686, Sir Isaac Newton proposed three laws to describe the motion of bodies. The first law of motion states that:

> A body will continue in its state of rest or of uniform motion in a straight line unless an external unbalanced force acts on it.

Newton's first law is also referred to as the **law of inertia**. The inertia of a body is the product of its mass and acceleration due to gravity. It is also the tendency of a body to remain at rest or if moving to continue in its motion in a straight line.

Inertia = mass × gravity

When a body is moving with a uniform speed in a straight line it needs force to sustain its motion unless an external force acts on it.

For example, passengers standing in a bus are very aware of their inertia. If the vehicle stops quickly they lurch forwards. Of course, they haven't really been thrown forwards. They have continued their forward motion

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> The rate of change of momentum of an object is directly proportional to the force acting on it and occurs in the direction of the force

The acceleration of a body is directly proportional to the resultant of the force in Newtons (N) acting on it and inversely proportional to the mass of the body.

$$a = dv/dt$$

or

$$F = ma$$

where a = acceleration, F = force and m = mass. Force is measured in Newtons (N), mass in kilograms (kg) and acceleration in m s^{-2}.

Force = change of momentum / time

$$F = m(v - u) / t$$

But the rate of change of velocity $(v - u)/t$ or acceleration. Hence, $F = ma$.

Newton's third law of motion

Newton's third law of motion states that:

> If an object A exerts a force on object B, then object B exerts an equal but opposite force on object A.

This tells us that forces come in pairs: consider what happens when a bullet is fired from a gun. The action force of the gun on the bullet is equal to the reaction force of the bullet on the gun.

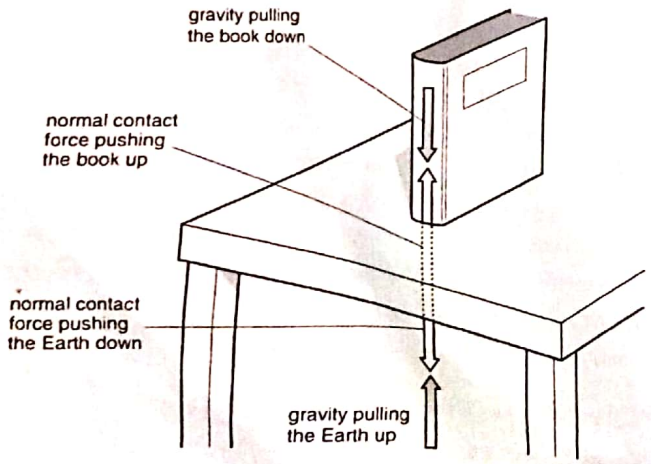


Fig 2.127 Pairs of equal and opposite forces.

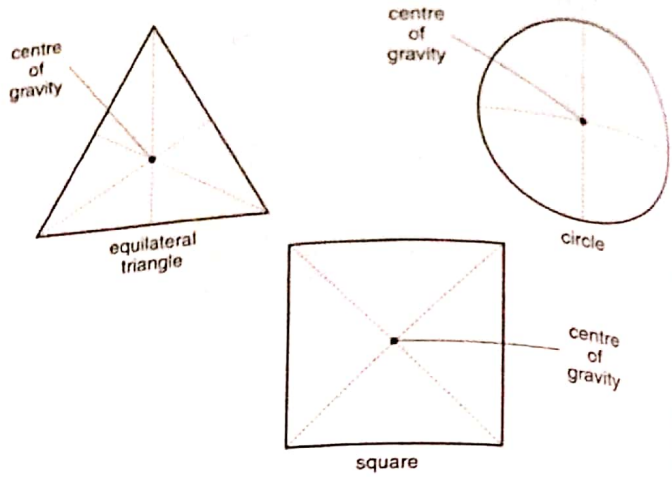


Fig 2.128 Regular laminae.

For a pair of equal and opposite forces to be an action and reaction the forces must be acting on different bodies and be of the same type. For example, consider a book standing on a table (Figure 2.127). There are two equal and opposite forces acting on the book. Gravity, pulling it down, is balanced by the normal contact force of the table pushing up. These forces are acting on the same body – the book – and are of different types, so they are not a Newtonian pair. If the book is body A, then the Earth is body B, so there is a pair of gravitational forces trying to pull the book and the Earth closer together. This pair is balanced by a pair of normal contact forces keeping the book and the Earth apart.

Centre of gravity

The Earth attracts all objects on it and near it. Each particle of a body is pulled to the Earth by gravity. The total weight of the body is the sum of the weights of all these parts. There is one point in a body at which all the forces on the particles in it seem to act. This is called the **centre of gravity** of the body.

If we take a **laminar** body (a flat sheet), we can find its centre of gravity by suspending it from different points on its edge and drawing plumb lines on it. The centre of gravity is the point where the plumb lines cross one another. Figure 2.128 shows some examples of regular laminae.

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at their original speed while the bus decelerated. The passengers grab something to provide the force needed to slow their bodies down. They will feel the opposite effect when the bus accelerates. Their inertia will keep them still while the bus accelerates, so they lurch towards the rear of the bus unless they hold on to something to provide the force needed to accelerate them. They will notice similar effects when the bus turns a corner; their inertia keeps them going in a straight line while the bus moves to the side as it goes round the corner.

If a force acts on a body, it will change its state of rest or state of motion in a particular straight line or will change its direction of motion. When a body travels in a circular orbit without changing speed, the force acting must always be at right angles to the direction of travel. This force is called **centripetal force** and it is directed towards the centre of the circle.

For example, the moon travels round the Earth in a circular orbit. Gravity provides the centripetal force and it pulls the moon in a circular path, without making it move any nearer to the Earth.

A force may also change a body's shape. Imagine a goat tied to a tether pulls on the string or rope. This produces a **tension** force in the string or rope. The increase in length or extension of the elastic string is proportional to the force. The same applies to a spring and the bending of a bow also depends on the force applied. If you hit a ball with a bat, you apply a force to it and the ball flies away from you.

ACTIVITY 3 Investigating the effect of a force on an elastic string or spring

1 Collect together an elastic string or elastic band, a set of weights and a ruler.

2 Measure the length of the unstretched elastic string.

3 Use the elastic string to lift the weights in turn and measure the length of the string for each weight. Put your results in a suitable table with correct headings. Work out how much the string stretches (the extension) for each weight and put these results in your table.

4 Draw a graph of extension against weight lifted. What does the shape of the graph tell you about the force and the extension of the elastic string?

An applied force may:

- cause a body at rest to move.
- cause a body in motion to increase or reduce its speed.
- cause a body in motion to change its direction of motion.
- cause a change in the shape of the body.

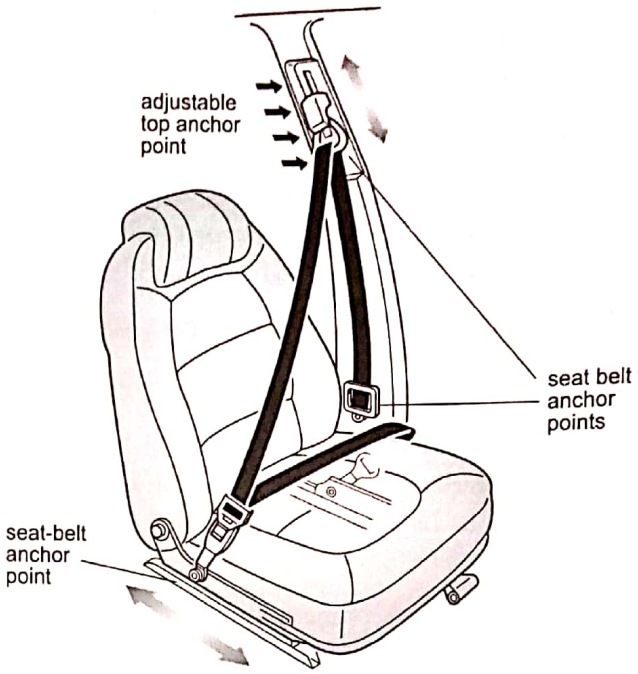


Fig 2.126 Seat belt fitted to the front seat of a car.

Seat belts

The purpose of a seat belt is to prevent the wearer from being thrown forwards and injured during a frontal impact (Figure 2.126). In a crash, a passenger's body has to slow down to zero in a fraction of a second from the speed at which the vehicle was travelling. If a vehicle travelling at 80 km h^{-1} is brought to rest in 0.6 seconds and the passenger weighs 75 kg, the force exerted on the passenger is more than 2700 N. This is almost three times the weight of a small car.

It is essential to have an automatic device such as a seat belt to restrain the body, because in a collision the time to act is too short – possibly as short as a tenth of a second – and the forces are too great to resist. Not only can passengers not react quickly enough to stop themselves but they also do not have enough force in their arms to do so. Seat belts have been developed to withstand this kind of force; they should always be worn.

Newton's second law of motion

Newton's second law of motion is also referred to as the **law of momentum** and states that:

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> The rate of change of momentum of an object is directly proportional to the force acting on it and occurs in the direction of the force

The acceleration of a body is directly proportional to the resultant of the force in Newtons (N) acting on it and inversely proportional to the mass of the body.

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or

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where a = acceleration, F = force and m = mass. Force is measured in Newtons (N), mass in kilograms (kg) and acceleration in m s^{-2}.

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This tells us that forces come in pairs: consider what happens when a bullet is fired from a gun. The action force of the gun on the bullet is equal to the reaction force of the bullet on the gun.

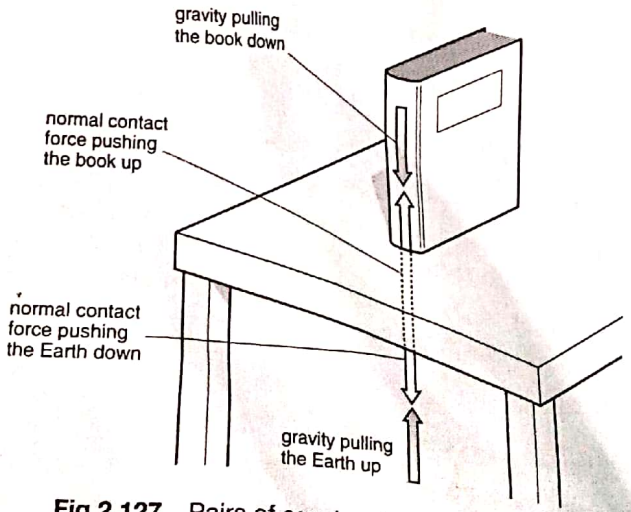


Fig 2.127 Pairs of equal and opposite forces.

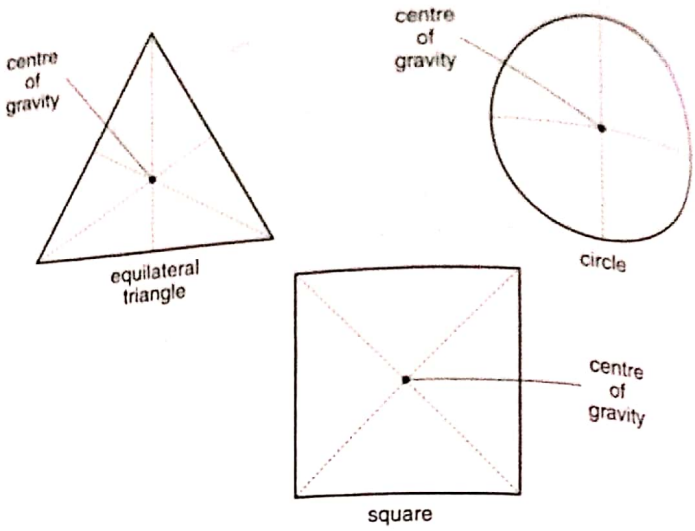


Fig 2.128 Regular laminae.

For a pair of equal and opposite forces to be an action and reaction the forces must be acting on different bodies and be of the same type. For example, consider a book standing on a table (Figure 2.127). There are two equal and opposite forces acting on the book. Gravity, pulling it down, is balanced by the normal contact force of the table pushing up. These forces are acting on the same body – the book – and are of different types, so they are not a Newtonian pair. If the book is body A, then the Earth is body B, so there is a pair of gravitational forces trying to pull the book and the Earth closer together. This pair is balanced by a pair of normal contact forces keeping the book and the Earth apart.

Centre of gravity

The Earth attracts all objects on it and near it. Each particle of a body is pulled to the Earth by gravity. The total weight of the body is the sum of the weights of all these parts. There is one point in a body at which all the forces on the particles in it seem to act. This is called the **centre of gravity** of the body.

If we take a **laminar** body (a flat sheet), we can find its centre of gravity by suspending it from different points on its edge and drawing plumb lines on it. The centre of gravity is the point where the plumb lines cross one another. Figure 2.128 shows some examples of regular laminae.

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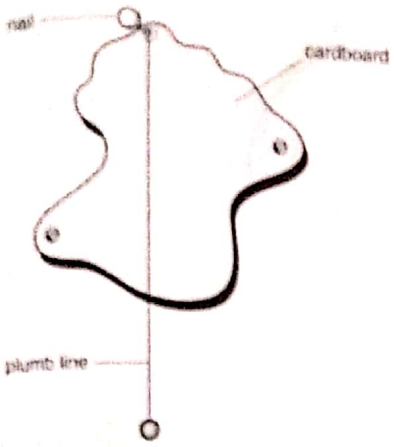


Fig 2.129 Centre of gravity of an irregular lamina.

ACTIVITY 4 Determining the position of the centre of gravity of an irregular-shaped lamina

1 Collect together an irregular-shaped piece of cardboard with three holes punched near its edge, a plumb line, a nail and a stand and clamp.

2 Fix the nail in the clamp and attach this to the top of the stand. Hang the cardboard from the nail by one of its holes. Hang the plumb line from the nail and mark the line of the string along the cardboard (see Figure 2.129).

3 Repeat step 2 using the other two holes. What do you notice about the lines you have drawn on the cardboard?

Centre of mass

In some bodies, the distribution of the mass (or particles) of the body is so irregular that the total mass appears to be centred at a point different from the centre of gravity. However, generally speaking, the centre of mass of a body and its centre of gravity coincide.

Stability

Any object standing on the ground or on a table has its centre of gravity above its base. What happens when it is displaced? This depends on how far its centre of gravity is moved. If a vertical line from the centre of gravity passes through the base, the object will return to its former position when released. However, if the centre of gravity moves outside the base the object will continue to fall over. If the centre of gravity of an object is always above the point of contact with the floor, the body remains in whatever position it is put after displacement. Figure 2.130 shows an example of this using a Bunsen burner.

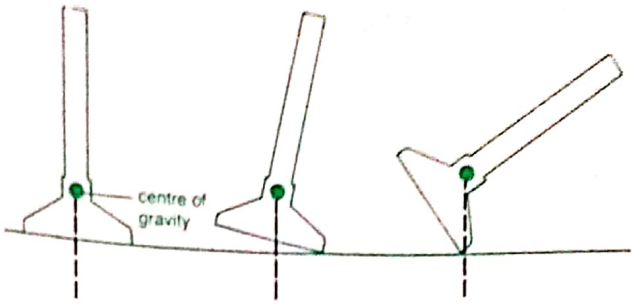


Fig 2.130 Stability of a Bunsen burner.

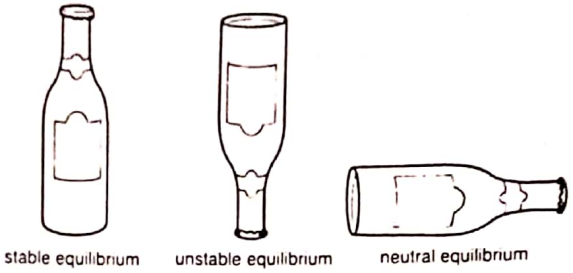


Fig 2.131 States of equilibrium.

States of equilibrium

A body that tends to be restored (or returned) to its former position after a slight displacement or tilt is said to be in **stable equilibrium**. The centre of gravity lies above the base area and is raised by the displacement.

A body that topples over and does not return to its former position after a slight displacement is said to be in **unstable equilibrium**. The centre of gravity lies outside the base and is lowered by the displacement.

A body that assumes a new position after a slight displacement is said to be in **neutral equilibrium**. The centre of gravity remains above the point of support or base; it is neither raised nor lowered (Figure 2.131).

ACTIVITY 5 Investigating stability

1 Collect together a flat board, a small box such as a matchbox and a protractor.

2 Place the box on the board and gradually increase the slope of the board until the box tips over. Measure the angle that the box makes with the horizontal when it tips.

3 Repeat the experiment with the other faces of the box on the board. Record the angle in each case.

4 Explain, with the help of a diagram, why the box falls over.

5 Repeat the experiment with a weight, such as a piece of modelling clay, stuck at one end of the box.

6 When is the box most stable and why?

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Vehicles and stability

When a vehicle travels around a bend, a **centripetal force** is provided by the friction between the tyres and the rough surface of the road. The vehicle will be in stable equilibrium, provided that the centre of gravity is low and the base is broad. Vehicles such as racing cars that are designed to drive around corners at high speeds are broad-based and have a low centre of gravity. This is to prevent them from toppling over at curves. Passengers are not allowed to stand on the top deck of a double-decker bus, as by doing so they would raise the centre of gravity and make the bus less stable.



Fig 2.132 Wide-tracked vehicle.

ACTIVITY 6 Class discussion about stability

Discuss the shift of the centre of gravity in the movement of:

- humans (a two-footed animal).
- a four-footed animal.
- a human on stilts.
- an acrobat walking along a tightrope using a pole.
- a man climbing a palm tree with straps.
- a car with a load on its roof.
- a clocktower in an earthquake.
- a woman carrying a load and a baby at the same time.
- spinning a pan with fingers or a stick.

Moment of force

The principle of moments states that a beam is in a state of equilibrium under the action of external forces when the sum of the clockwise moment of all the forces about the pivot (fulcrum or axis of rotation) is equal to the sum of the moments of forces in the anti-clockwise direction about the same point.

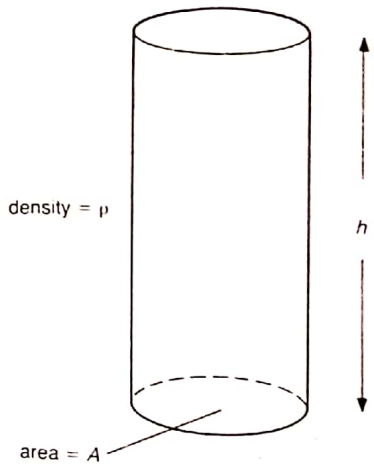


Fig 2.133 Pressure in a column of liquid.

Pressure

When a force is exerted on a surface, the force per unit area is called the **pressure**.

Pressure = Force / Area

When the force is measured in Newtons and the area in metres squared (square metres), the pressure is given in Newtons per square metre ($N\ m^{-2}$), which are usually called Pascals (Pa).

Caterpillar vehicles and tractors usually have extra-wide wheels (Figure 2.132). This increases the area in contact with the ground and reduces the pressure that they exert. This prevents them from sinking into soft ground. Sharp-pointed shoe heels sink deeper into the ground than broad flat heels because the pressure is greater at the point of contact with the ground. The same is true of a sharp-pointed peg, which is easier to drive into the ground than a blunt peg.

Pressure in liquids

In Figure 2.133, a column of liquid of height h covers an area A and the density of the liquid is ρ. Then:

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Volume of liquid = Height × Base area = hA
Mass of liquid = Density × Volume = $hA\rho$
Weight of liquid = Mass × g = $hA\rho g$
Pressure exerted at base of the liquid =
Force/Area = $hA\rho g / A = h\rho g$

The pressure at a given point below the surface of a liquid depends on the depth and the density of the liquid. If you dive into water, the pressure exerted on you increases uniformly with depth. In the oceans, pressure increases by one atmosphere for every ten metres of depth.

ACTIVITY 7 To show that pressure in a liquid varies with depth

1 Collect together a cylindrical vessel about 20 cm high with holes of equal diameter in the sides at regular intervals from the top.
2 Stand the vessel next to a sink and fill it to the top with water.
3 How far does each jet of water reach? What does this suggest about the pressure at different distances below the surface of the water?

The hydraulic press

The transmission of pressure through liquids is called **hydraulics**. When a fluid completely fills a vessel and pressure is applied to any part of the surface, the pressure is transmitted throughout the liquid in the vessel. This is known as **Pascal's principle** and it has several useful applications including the hydraulic press.

In the hydraulic press shown in Figure 2.134, if pressure is applied in the left-hand cylinder, the same pressure is transmitted to the right-hand cylinder. Since the area of the right-hand cylinder is greater, it follows that the force exerted by the ram is greater than the effort. Hydraulic presses are used to compress soft materials, such as paper and cotton, into bales and to press sheet metal into shapes for use in products such as motor car bodies.

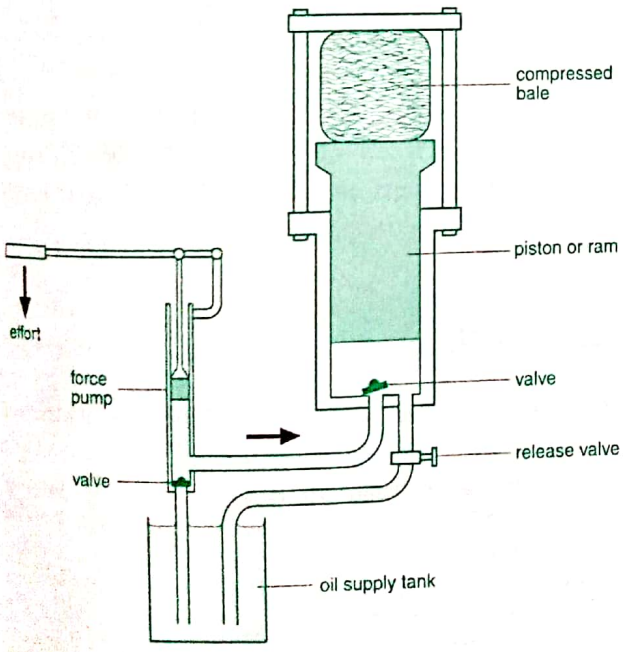


Fig 2.134 The hydraulic press.

Pressure in air

ACTIVITY 8 To demonstrate that air exerts a pressure

Caution: Boiling water can burn your skin.

1 Use a 4.5 litre can with a tight-fitting lid or screw cap.
2 Put water in the can to a depth of 2 or 3cm. With the lid open, heat the can until the water boils and steam comes out of the can (Figure 5.2.14).

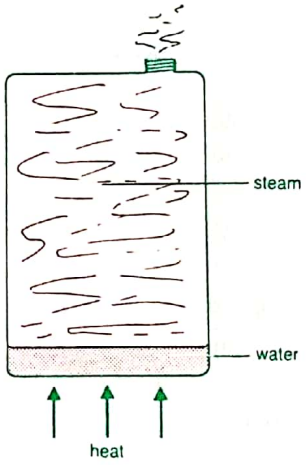


Fig 2.135 Air exerts a pressure.

3 Remove the source of heat and carefully place the lid or screw cap tightly on the can to seal it.
4 Allow the can to cool.
5 Note what happens to the can.

The crushing-can experiment demonstrates the effects of atmospheric pressure. When the water boils, steam displaces air from the can. The steam pressure

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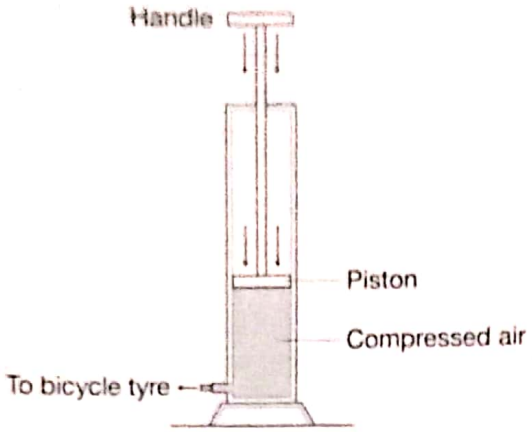


Fig 2.136 A bicycle pump.

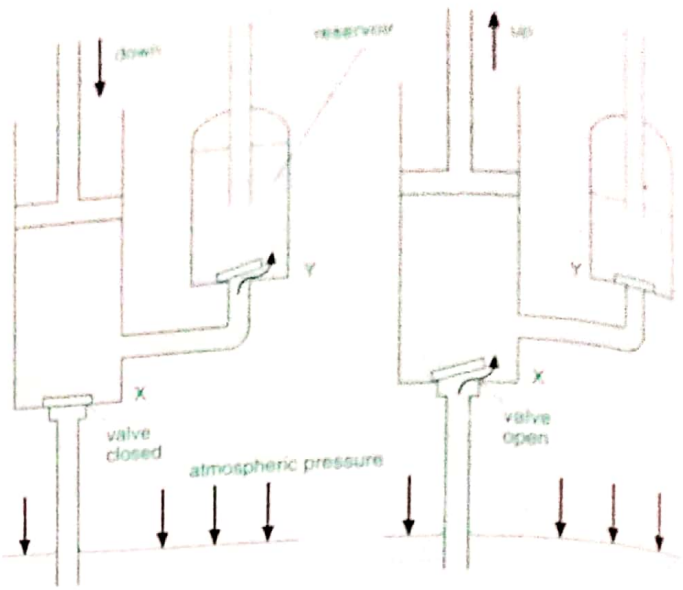


Fig 2.137 Water pump (force pump).

inside the can is equal to the air pressure outside but when the can is sealed and allowed to cool the steam condenses and the pressure inside the can falls. The atmospheric pressure outside the can is thus greater than the pressure inside the can: the resulting force on the outside of the can crushes it.

Normal atmospheric pressure is approximately equal to 100 000 Pa.

The bicycle pump

Bicycle pumps are used to pump air into bicycle tyres, footballs and some balloons. It has a cap-shaped leather washer fixed to the end of the piston rod that moves up and down the barrel of the pump (Figure 2.136).

When the handle is pulled up, air flows into barrel through a tiny hole between the leather washer and the barrel. When the piston is pushed down the valve closes to prevent the air that has entered the barrel from leaking out. The air is then compressed through the hole at the end nozzle into the bicycle tyre or football. This process is repeated until air fills the tyre. The tyre is then said to be inflated.

Water pump

A water pump is also referred to as a force pump. They are used to raise water in the ground to a height of about 10 m.

Down stroke

On the down stroke, valve B closes and water is forced into chamber C through valve A by the pressure exerted through a mechanical force on the plunger (Figure 2.137).

The exit pipe P projects into the chamber C to trap air at the top of the chamber. The trapped air acts like a cushion or spring to prevent the pump from jolting up suddenly when the water column in P falls slightly and suddenly closes valve A at the beginning of upstroke. The chamber C holds the water and sends it through the tube that leads outside, during the upstroke.

The maximum height to which water can be lifted in a water pump depends on: the force exerted on the plunger during the down stroke and the efficiency of the working parts of the pump to withstand the pressure the column of water in the exit pipe.

Upstroke

On the upstroke, the valve A closes and the atmospheric pressure pushes water up into the chamber through valve B. The upward movement of the plunger sends water out through the exit pipe.

Self check

For questions 1 to 4, choose the letter that refers to the correct option.

1 Which one of these forces cannot act at a distance and must have physical contact between two or more bodies?

A frictional force
B gravitational force
C magnetic force
D electrostatic force

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3 When three or more forces acting on a body are in equilibrium:
I There is no resultant force
II The body must be stationary
III The point of application of the forces moves in the direction of the largest force.

A Only I is true
B Only II is true
C Only III is true
D I, II and III are all true

4 A submarine at a depth in the sea will re-surface when
A the pressure on it is reduced
B its speed is reduced
C water is pumped out of it
D air is pumped out of it

5 What forces are exerted when:
a) a locomotive engine is coupled to a train of coaches?
b) a bird sits on a perch?
c) a snail crawls along a glass pane?
d) an athlete sprints at the start of a race?

6 a) What is the quantity of matter a body contains called?
b) What is meant by the weight of a body?
c) In what units are mass and weight measured?

7 Explain why a fresh egg will sink in clean water but float in a concentrated solution of salt in water.

8 What is pressure?

9 A concrete block weighs 1500N. The dimensions of the block are 30cm × 40cm × 50cm.
a) On which side should the block be stood in order to exert least pressure on the ground? What will be the value of the pressure?
b) On which side should the block be stood in order to exert most pressure on the ground? What will be the value of the pressure?

10 a) What is meant by a change in velocity?
b) What causes a change in velocity?
c) A body moving with uniform speed in a circle is said to be accelerated although there is no change in its speed. How is this possible?

11 a) An athlete at the start of a race accelerates at 5 ms^{-2}. If she has a mass of 500N, what is the resultant force acting on her?
b) Where does the force comes from?
c) What is her momentum when she has reached a speed of 7 ms^{-1}?

12 a) Draw a picture of a kite being flown. Add arrows with labels to your picture to show the forces acting on the kite and the direction of these forces.
b) What can you say about the forces acting on the kite if:
(i) it is hovering at the same point
(ii) it is moving vertically upwards at a constant speed
(iii) it is accelerating vertically upwards.

13 a) What force provides the centripetal force when a car turns a corner in a road?
b) On which body and in which direction does the centripetal force act?
c) Explain the effects the passengers feel if a car goes round a corner quickly.

14 Draw the outline shapes of the following and for each explain why it has the shape you have drawn:
a) an aircraft body
b) the hull of a boat
c) a fish that can swim quickly.
Why is it more difficult to pull a log through water quickly than a boat of the same weight?
Why is the shape of a satellite not important in its design?

15 a) What is the difference between a blunt and a sharp knife?
b) Why is it easier and safer to carve a stick with a sharp knife than a blunt one?

17 a) What is pressure?
b) Describe an experiment to show that pressure in a liquid increases with depth.

18 a) Define the centre of gravity of a body.
b) Name the states of equilibrium of a body.

19 Explain:
a) why it is more suitable to locate the load compartment of a bus under the passenger seats than at the top of the bus
b) the importance of wearing seat belts in moving vehicles.

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3 Safety in the community

Learning objectives

After studying this unit, you should be able to:

1 identify appliances used at home and how to use them properly
2 use first aid methods to treat accidents at home
3 identify hazardous substances at the work place and their effects on humans
4 identify some common hazards in the community
5 outline the role of organisations working to improve the health of mankind and the factors that promote Public Health.

Background information

A **hazard** is something that can cause an accident or harm to something. It can be an element or substance that can burn, pollute the air or water or destroy the quality of the soil.

Hazardous chemicals such as acids and alkalis can cause harm to the skin, eyes and other organs of the body.

Chemicals such as DDT can pollute water and air and kill aquatic animals such as fish and other living things.

Wastes that are not properly managed can be hazardous to human health.

Many substances in the home and in some workplaces are hazardous and call for effective management.

In the home there is always the risk that a fire may start from a fuel or energy source. Energy is needed for many purposes in the home, such as cooking, lighting and cooling. Some forms of lighting, heating and cooking use naked flames. Other appliances, such as heaters, stoves, irons, lamps, ovens and microwave ovens, radio and television sets, are powered by electricity. Any mishandling of these appliances can produce undesirable results.

Many accidents in the home are caused by carelessness. A wet floor can be slippery. An uneven surface can cause someone to trip. Anyone can hurt themselves if they fall and in an elderly person, a fall may cause serious injury.

Appliances used in the home

In many homes, appliances are used for activities such as:

- maintenance of health
- food preparation
- communication and entertainment
- sanitation
- hobbies
- maintenance and repair work.

Maintenance of health

In homes, drugs are administered to treat the sick. Some of these drugs are prescribed by qualified medical personnel but as a result of poverty and the inaccessibility of hospitals and clinics many people use drugs offered by well-wishers, the concoctions of herbalists and sometimes medicines that should only be prescribed by doctors, such as antibiotics. Drugs that are beyond their expiry date are also dangerous, no matter how cheap they may be.

Drug abuse is hazardous to health. 'Quack' doctors administer injections that kill, maim or create horrifying problems.

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It is advisable to report all diseases to hospitals. The introduction of the Health Insurance Scheme in Ghana should mean health hazards in homes are reduced.

Food preparation

Gadgets for food preparation use electricity, liquefied petroleum gas, wood fuel or charcoal as a source of energy. When electric cables are not properly insulated, contact between bare wires can cause sparks, which may cause fires.

Electric shocks are associated with faulty cooking gadgets. Such shocks can be fatal. Similarly, gas cookers that leak gas can be fatal when the gas is inhaled or a live flame comes close to the gas.

Apart from gadgets, canned foods that have expired are often poisonous and can kill when consumed. Hot oil can spurt and scald the body and sharp cooking knives can prove hazardous when the user loses concentration. Low-cost spoons manufactured from metals such as lead can be poisonous.

Bottles which act as containers for oil, salt, sugar and soft drinks can be hazardous when broken or when pieces peel off and mix with the salt or sugar. When such sharp pieces of bottle are swallowed with food they are harmful.

Communication and entertainment

Communication equipment, such as computers, fax machines and cell phones, needs regular maintenance to prevent outbreak of fire or release of harmful radiant waves. Videos, TVs, films and tape recorders are sources of entertainment in some homes. When these useful gadgets are not properly maintained they pose hazards in the home – fire outbreak and release of fumes have been reported. Frequent exposure to very loud noise from speakers in a small room can lead to deafness.

Sanitation

Failure to wash hands thoroughly with soap can spread dysentery and diarrhoea. An unscrubbed toilet and bathroom pollutes the air in the home. The toilet and bathroom should be cleaned regularly. Slippery tiles are sometimes used to cover bathroom or kitchen floors. If water spills onto these tiles, walking becomes risky.

Hobbies

Tools such as needles, knives, raffia and canes are used in hobbies such as basketry, sewing door mats and the backs of chairs. If these tools are not properly handled and kept in a safe place injuries may result from them. **Rusty tools are a potential source of tetanus.**

Maintenance and repair work

Maintenance and repair of broken-down electrical equipment and gas cookers must be done by experts to avoid burning and electric shocks.

Safety in the home is the collective responsibility of all the occupants of a house.

ACTIVITY 1 Identifying possible accidents in the home

1 List appliances that are used in the home, such as electric irons, televisions or gas cookers and identify possible accidents that might result from their improper use or handling.

2 Use your list as the basis for a class discussion on accidents in the home and how to avoid them.

Precautions against accidents in the home

Fires may be started by careless handling of lighted candles or other naked flames which set papers, clothes and furniture on fire. Materials that can catch fire easily include wood, thatch, plywood, foam, curtains, polythene, plastics and petrol. This can result in the destruction of property, injury and even loss of life.

Petrol evaporates easily and is very flammable. The vapour may leak out to a naked flame and catch fire, so that the fire burns back along the trail to the source and sets the store on fire. Naked flames, lighted cigarette stubs or even mosquito coils should not be placed anywhere near garages or where petrol is stored.

Where bushes are near cottages the bush should be cleared some distance away from the village huts so that, if there is a bush fire, it will not spread into the village.

Many villages are now connected to the national grid. The hazards from electricity are fires and electric shock. These are often caused by faulty or damaged wiring in electric circuits. Naked wires or cables should be covered in insulation and under no circumstances should be handled with bare hands.

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At high voltages, water can conduct electricity. Do not touch electrical switches or equipment with wet hands. Water could run inside the switch and conduct the electricity to you, giving you an electric shock. Use dry, non-conducting objects such as wooden poles to push wires out of the way, should this be necessary. Rubber boots or shoes insulate the wearer. Do not touch the victim of an electric shock until all electrical connections have been removed. If you touch a person receiving an electric shock you will receive one as well.

Make sure that electrical appliances such as stoves and fridges are correctly wired, without any part of the wiring being exposed. They must be earthed so that if any wiring is exposed and a wire touches the metal casing, it does not become live. The correct wiring for a plug is shown on page 278.

It is important not to **overload** electrical sockets by plugging too many appliances into them. This could cause them to overheat and possibly catch fire.

Care must be taken with the positioning of electrical flexes. They must not be placed where people could trip over them or where they could get trodden on. It is very dangerous to run a flex under a carpet or rug.

Accidents in the home

Accidents in the home include burns from things such as hot oils and hot water (scalding), hot metals such as pokers, irons and ladles and hot air from ovens, chip pan fires, where the cooking oil gets so hot that it catches fire in the pan and burning materials (such as foam) that produce toxic fumes that can choke the victims of fire (fire-fighters wear gas masks to prevent breathing in the toxic fumes).

Fires

Make sure you know the telephone number of the fire service station in your locality. If there is a fire, put a call through immediately. Give correct directions for them to locate the spot. Know what kind of fire extinguisher is appropriate for the kind of fire and use it if available.

Keep yourself safe. Do not take risks that put you in danger.

A fire needs three things to keep burning: fuel, air (or more correctly, oxygen) and heat. Remove any one of these and the fire will go out.

There are many different types of **fire extinguisher** or substances that you can use to extinguish a fire.

- **Water** cools and can be used to put out many fires except those caused by faulty electric circuits, petrol and paraffin fires and burning oil.
- **Foam extinguishers** (not common in Ghana) cover the fuel with foam and keep the oxygen away. However, you must not use water-based foam on electrical fires.
- **Sand** (which must be dry) covers the fire and keeps oxygen away. It is safe to use on any fire.
- The gas produced by **carbon dioxide extinguishers** is heavy and displaces air (and therefore oxygen) around the fire. They are safe to use on all fires.
- **Dry powder extinguishers** (not much used in Ghana) are safe to use on all fires, as the powder covers the fire and keep oxygen off the fuel.
- **Fire blankets** (or any damp blanket or sack) are particularly useful in fires on clothing; you can wrap the blanket round the person and get them to roll on the ground. A fire blanket or damp sack is also suitable for putting out a chip pan fire.

If there is a fire in the house:

- Switch off the electricity supply and remove the main fuse.
- Use a suitable fire extinguisher to put out the fire, if available.
- Treat any person in shock by keeping them warm and give first aid where necessary.
- Take any victims to a hospital.

First aid methods

Small wounds

Small wounds can be allowed to bleed freely until the blood clots. The blood will help to wash away dirt. To avoid any chance of infection it is wise to wash the wound with clean water or disinfectant. Then cover the wound with clean absorbent cloth or sterilised medical dressing. Change the dressing daily until the wound has healed.

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Large wounds

Large wounds may bleed so quickly that clotting cannot occur. It is therefore important to stop the flow of blood or at least slow it down.

Severe bleeding, with the blood flowing out rapidly, must be stopped at once by pressing with the fingers directly on the wound or by pressing the edges of the wound together for at least ten minutes. There will be no time to search for sterile dressings or bandages. Lay the patient down and, if the wound is in a limb, raise it, unless it is fractured. When the bleeding has slowed down, press a pad of material over the wound and tie it firmly in place. If more blood oozes through, apply more material on top of the original pad.

It may sometimes be impossible to get the edges of the wound together because the injury has removed so much tissue. In this case, if bleeding is severe, a dressing must be placed in the wound to plug it. The 'dressing' may have to be a vest or a shirt if you are not carrying a first aid kit. It is more important to stop the bleeding than to worry about infection. Rapid loss of blood may lead to death in as little as twenty minutes and the patient may not reach hospital alive. If the blood loss is stopped and the casualty gets to hospital, the medical staff should be able to treat any infection introduced by the dressing.

Sprains

A sprain is a torn ligament or muscle. Avoid putting weight on the joint. Raise the limb. Apply a cold compress and keep it in place with an elastic bandage.

Burns and scalds

A **burn** is caused by dry heat, such as a flame or hot object. A **scald** is caused by steam or boiling water.

For scalds, any wet clothing should be carefully removed but burned clothing should be left in place. Flood the burned or scalded area with clean, cold water for at least ten minutes or, in the case of hands and arms, to immerse the limb in running cold water.

Do not apply any ointments or lotions but lightly cover the injured area with clean, dry cloth to keep bacteria from falling onto the damaged tissue. Remember that shock is likely to result from burns that affect a large area of skin.



Fig 2.138 Securing an injured arm if the elbow cannot be moved.

Fractures

Prevent movement in the area of the fracture until qualified medical personnel arrive. If you *must* move a casualty, support the injured part with padding or your hand. For a short journey to hospital, you may be able to immobilise the injured part by securing it to a sound part of the body using padding and bandages (Figure 2.138). Bandages must be firm but not so tight that they affect the blood circulation. For a long journey over rough ground, you may need extra bandages and splints. You can use virtually any suitable strong stick or piece of metal as a splint – even rolled-up newspaper. Keep checking to ensure that the bandages are not too tight.

Reducing the effects of shock

If a person has been injured they often become quite weak because they are in a state of shock, caused by the loss of blood pressure. The symptoms of shock are a rapid, weak pulse; cold, damp skin and shallow, rapid breathing.

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You should assume that the patient is shocked in all cases of electric shock, drowning, burns and serious injury.

Keep the patient lying down, with legs raised if possible to maintain the blood pressure to the brain. Do not give anything to drink and do not try to warm the patient but loosen any tight clothing round the neck, chest and waist. Do not move the patient more than is necessary for their safety.

The treatment for shock is to restore the blood volume by transfusing blood or plasma and the patient must be sent to hospital as soon as possible.

Resuscitation

Mouth-to-mouth ventilation

Exhaled breath contains about 16 per cent oxygen, which is enough to oxygenate the casualty's blood.

Remove any obvious obstructions from the casualty's face and loosen their collar. Turn the casualty carefully on their back, tilt the head back as far as possible and pull the jaw forward, opening the mouth (Figure 2.139). This will open the windpipe. Open your mouth wide and place it over that of the casualty; close the casualty's nostrils by pinching their nose with your fingers. Sealing your lips around the mouth, blow gently into the casualty's lungs until you can see the chest rise. Then remove your mouth well away from the casualty's and breathe out any excess air. Watch the chest fall, then take a fresh breath and repeat the procedure. Check the casualty's pulse to ensure that the heart is beating. If it is not, you must carry out external chest compression straight away.

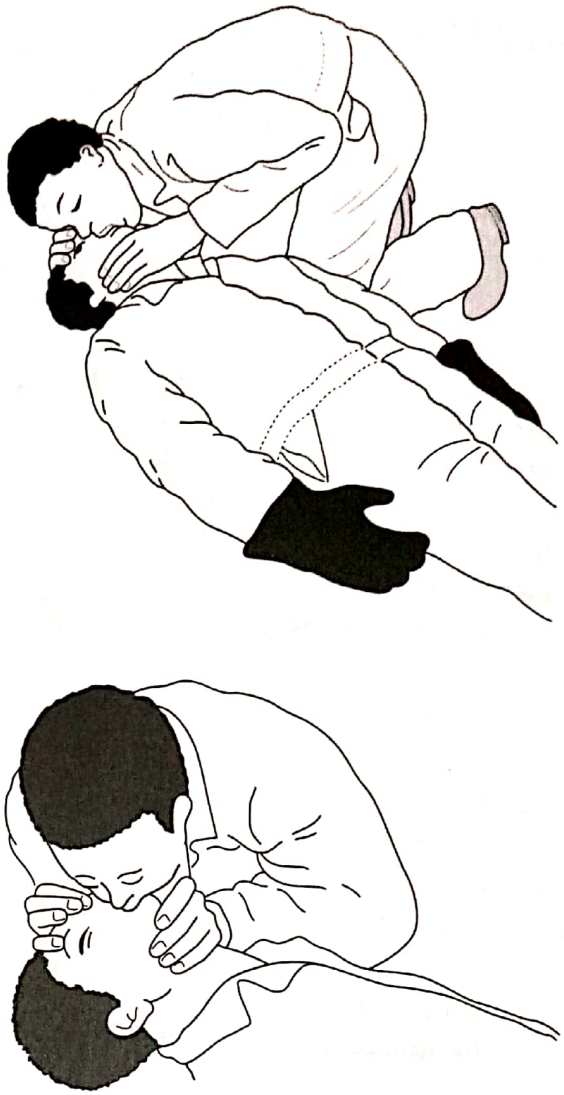


Fig 2.139 Mouth-to-mouth ventilation.

External chest compression

Lay the casualty on their back and kneel alongside them. Place the heel of one hand in the centre of the lower region of the breastbone, keeping your fingers off the ribs. Cover this hand with your other hand and lock your fingers together (Figure 2.140).

Keeping your arms straight, move forwards until your arms are vertical. Press down on the lower part of the breastbone; about 4–5 cm for an average adult. Then move backwards, releasing the pressure. Perform 15 compressions at the rate of about 80 per minute. Then move back to the casualty's head, reopening the airway and giving two mouth-to-mouth ventilations.

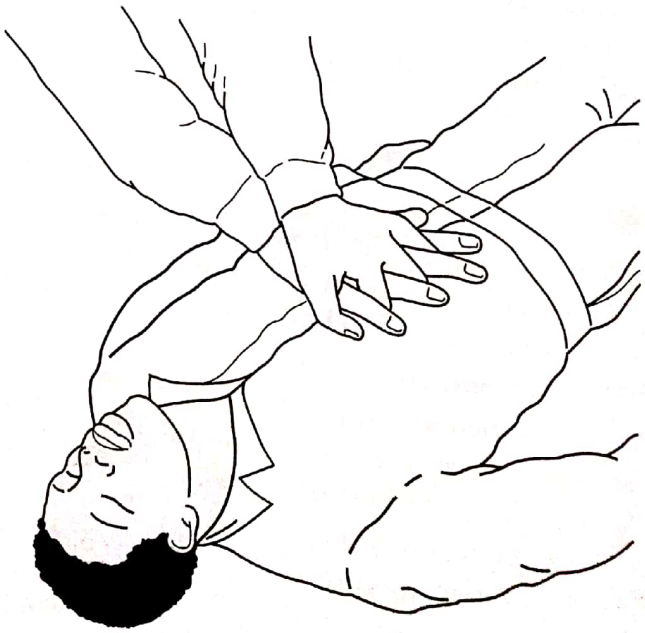


Fig 2.140 External ch...

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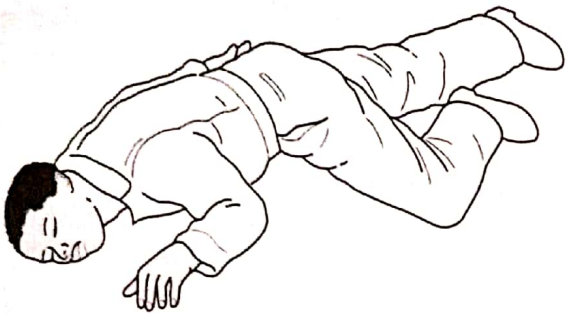


Fig 2.141 The recovery position.

Continue giving 15 compressions followed by two ventilations, checking for heartbeat after one minute. Continue, checking the heartbeat every three minutes. As soon as the heartbeat returns, stop compression and continue mouth-to-mouth ventilation until natural breathing returns. Place the casualty in the recovery position (Figure 2.141).

Carefully move the arm from under the casualty and place it parallel, to prevent them from rolling on to their back.

Hazardous substances and their effects

In the home, substances such as petrol, kerosene and acids that are highly inflammable are dangerous. Liquid petroleum gas, used for cooking and other activities, though useful, can be a source of worry when improperly controlled or exposed to naked flames.

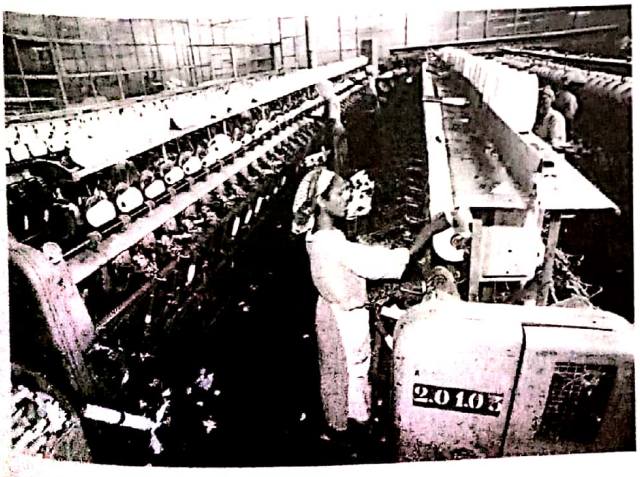


Fig 2.142 Modern machinery is useful but has its hazards.

Electric cables that are not insulated, or faulty gadgets, can cause serious harm to humans and domestic animals.

ACTIVITY 2 Identifying hazardous substances in the home

1 List as many substances as possible in the home or workplace that are hazardous, using the following criteria:
   - **a)** highly inflammable
   - **b)** corrosive
   - **c)** irritating on contact with the skin
   - **d)** sending out unhealthy odour
   - **e)** easily reacting with other substances
   - **f)** producing toxic fumes
   - **g)** exploding on contact with heat
   - **h)** food contamination
   - **i)** slippery substances.

2 Write a short essay about possible hazards that can happen in a workplace and trace the possible causes of such hazards.

3 Make a chart of any ten hazardous substances in the home and the effects they could have.

Hazardous substances and the human body

The skin is a cover for vital tissues in the human body. Damage to the skin can cause bleeding, scalding and in some cases infections. The skin gives the body its beauty and appeal.

Chemicals can harm the skin by burning, scalding, piercing, causing itches and sometimes peeling cells off the body. Substances that burn the skin include fires, toxic sprays, concentrated acids and alkalis. Acids scald the skin and create unwanted permanent folds and contortions that are unpleasant to see. When this happens to the face the natural beauty and attraction may be lost forever.

Hot oils or acids coming in contact with the skin can scald it. This can also happen as a result of bleaching the skin with strong soap, creams and sprays.

Thorns can pierce the skin, causing bleeding and infection. Danger is also posed by sharp objects such as blades, nails, needles and pins which are carelessly scattered in the seamstress's or tailor's shop or in our homes.

Powdering and spraying certain parts of the body improves the smell. Powder, sprays and creams that

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are uncertified are often hazardous and may cause skin rashes.

Itches

Infections can create itching skin but wild plants can cause even worse skin problems. Similar hazards can be soaps and lotions to which the skin is allergic and bites from some flies and insects.

We need to keep away from people infected with chicken pox or measles, since such infectious diseases can be harmful to the skin. Worm infection can cause irritating skin problems.

Environmental hazards

Some substances are hazardous to the environment as well as to humans. Some chemicals that can harm humans are also harmful to water, plants and the soil. Mismanagement of waste and unclean drainage is hazardous. Disease germs are incubated and released to create epidemics and diseases. Mosquitoes breed and attack humans when drains are not cleaned. Poor environmental sanitation is hazardous to our health.

ACTIVITY 3 Finding out about pollutants

Work in groups to discuss the effect of the following on the air, water and soil.

	Effect on			
Name of pollutant	Air	Water	Soil	Plants
Smoke from factory chimneys				
Spilled petrochemicals				
DDT				
Heap of garbage (waste)				
Solid waste (toilet)				
Radioactive substances				
Pesticides				

Workplaces have particular significance in terms of hazards, since people spend much of their active life at their workplaces. It is essential that people know of the hazards that exist at work. People should be able to identify the hazards and to appreciate their effects on health and the environment, in their daily life and at danger.

An **occupational hazard** is any risk or danger associated with a particular job or profession. An **occupational disease** is any disease arising from exposure to an occupational hazard.

For example, the health of a teacher or radiology technician who uses chemicals or radiation equipment may be at risk. The chemical substances could be toxic or cause cancer or the radiation equipment could allow harmful radiation to escape. Students present in the class could be exposed to the hazards.

Special procedures have been developed for the workplace and the home to prevent accidents or minimise their effects on people's health and on the environment. These include laws and regulations, safety conventions, posters, First Aid, medical treatment and labour.

Workplaces vary greatly in terms of the number and types of hazards to which people are exposed. Common hazard types include:

- dust
- fumes
- toxic gases
- corrosive substances
- fire and explosions
- electrical shocks
- food contamination and poisoning.

Not only humans are affected by hazards; many hazards pose dangers to plants and to other animals.

Dust

Dust is a potentially serious hazard but its effects are often taken lightly. Dust coming from deserts, dirt roads, building construction, quarrying, mining and rubbish dumps is carried on the wind (Figure 2.145). Other types of dust are hazards in factories that produce items such as cement, asbestos, cement and chemicals.



Fig 2.143 Dust is carried on the wind.

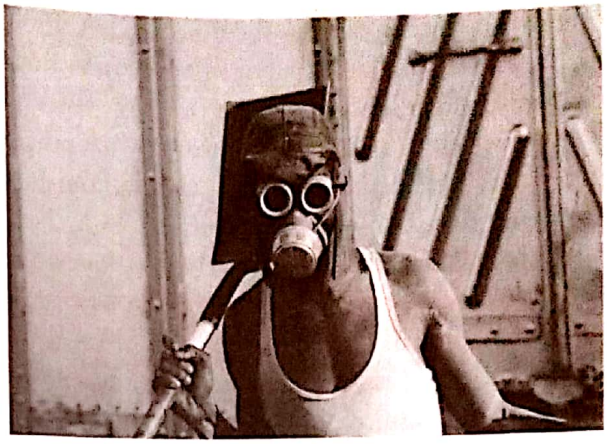


Fig 2.144 Face masks protect the lungs from dust.

Dust particles are small, fine, solid particles suspended in air or settled. They are formed when solids break down into small particles. They may be referred to as **particulates**. Any solid material can form dust.

Most dust particles are so fine they cannot be seen by the naked eye. The finer the dust particles, the more easily they are inhaled. There are always dust particles floating in the atmosphere. These are referred to as 'background dust' and are seldom dangerous.

Dust particles are constantly formed. They move with the wind and may settle on surfaces and become visible after a while.

Any person constantly exposed to dust particles is likely to contract a respiratory disease. Dust emissions from many factories are occupational hazards. In some factories, systems of tubes draw in air and filter it to remove dust. Where dust is a hazard, workers should be provided with suitable protective equipment, such as respiratory masks (Figure 2.144). The masks prevent workers from breathing in dust and so prevent damage to the respiratory system. In many countries, employers are required by law to provide suitable protective clothing for their employees and give them regular medical checks.

If a dust mask is not available when there is dust in the air, the nose can be covered with a clean porous cloth. This provides some protection for a short time.

Atmospheric dust serves as nuclei (starting point) for condensation of water vapour into rain clouds, mist and fog.

Fumes and fires

Fumes are any smoke, gas or vapour that smells strongly. Fumes may have an irritating, sharp or pungent smell. They may also have an offensive smell or be poisonous (toxic). Many substances start to burn above a certain temperature.

Fires give out heat. The heat sustains the fire as long as combustible materials are still present.

The temperature at which a material can start to burn is called its **ignition point** (or **flash point** for liquids). **Combustion** is the chemical reaction between a combustible substance and oxygen (air).

Fire results from combustion. It produces heat and light.

Fumes can be produced by decaying organic materials such as food in the kitchen or on refuse sites. Fumes may also come from chemicals, volcanic eruptions, explosives, fuels and the combustion of fuels.

Some chemical fumes, such as those from concentrated hydrochloric acid and ammonia solution,

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are corrosive and irritating to the nose. A host of organic solids and liquids give out fumes under normal conditions; these become more intense when the substance is heated or burned. Ethoxyethane, ethanoic acid, ethanal and ethylamine are examples of substances with sharp smells. Hydrogen sulphide, H_2S, has an offensive smell of rotten eggs and is highly poisonous in large quantities.

Large amounts of fumes, in the form of smoke and vapour, are formed in large domestic and factory fires, at sea, when fuels ignite and during bush and forest fires. Heavy smoke and vapours, produced during fires, can be damaging to humans, to other animals, to property and to the environment. Toxic vapours pollute the air. Toxic vapour, such as carbon monoxide, is a major killer in household fires. When inhaled, carbon monoxide causes suffocation.

Explosions may also occur as a result of fires.

Fires are fuelled by flammable materials for example, wood, paper, grass, plastics, oils, fuels, paints and flammable chemicals such as ethanol, charcoal and kerosene. If any of these are present the fire will increase in intensity. Temperatures may rise to levels above which the solids or their liquids or vapours burn. If a fire gets hot enough, substances which do not burn under normal conditions will burn. Fires rely on a good supply of oxygen from the air. If the air supply to the fire is reduced or removed the fire will be extinguished.

Plastic materials, especially polyurethanes, produce poisonous fumes when they burn. Many materials in the home, such as foam mattresses and furniture, insulation on wires, curtains and some carpets contain plastics which burn freely or produce smoke (Figure 2.145).

In a fire, hot smoke and gases rise towards the ceiling because hot air is less dense than cold air. In the early stages of a fire, this can save life. If you lie face down on the floor where there is no smoke, and quickly crawl to the nearest door, window or sizeable opening you can get away from the fire.

A victim of fire risks death from suffocation and/or the effects of toxic fumes as well as burns to the body.

Contact between flammable materials and an appropriate amount of heat energy starts fires. The heat energy may be provided by a naked flame or other source, such as a cigarette stub. Electrical devices can overheat causing wires to become red hot and melt the plastic insulation that surrounds them. Sparks resulting from a short circuit may be sufficient to start a fire.



Fig 2.145 The foam used in furniture gives off poisonous fumes when it burns; the hot smoke and gases rise to the ceiling.

Managing fires

Most fires start small and grow bigger if not extinguished. Small fires anywhere must first be fought with fire extinguishers and fire blankets. If this does not stop the fire and it gets out of control, the fire service should be called in immediately.

Firefighters should be called to tackle large fires which cannot be controlled. They should be contacted by telephone or by other quick means. The telephone number(s) of the nearest fire-service stations must be known or easily accessible in homes, schools, workplaces, etc. to avoid any delay.

Firefighters are experts who have been specially trained in methods of fighting fire. They wear special clothes and, when necessary, use breathing masks to supply sufficient oxygen for breathing and to prevent the effects of smoke and toxic gases. Modern firefighters are well educated and trained professional workers. It is a tough but interesting career.

When a fire occurs, whether or not it is from an electric source, the main electricity supply to the building should be turned off at the main switch. This is to reduce

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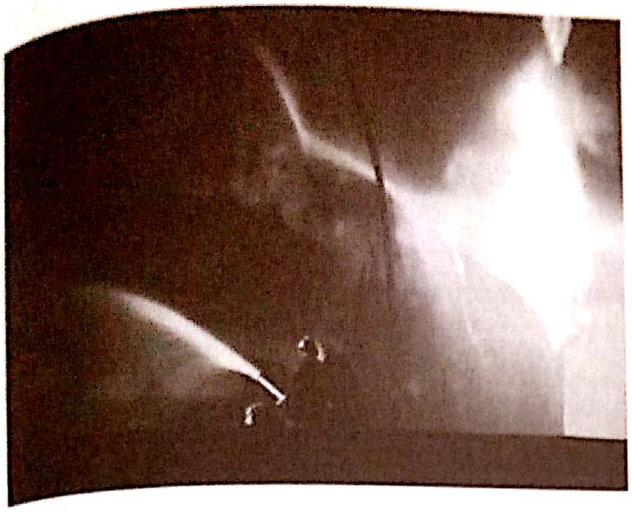


Fig 2.146 Large fires are best left to professional firefighters.

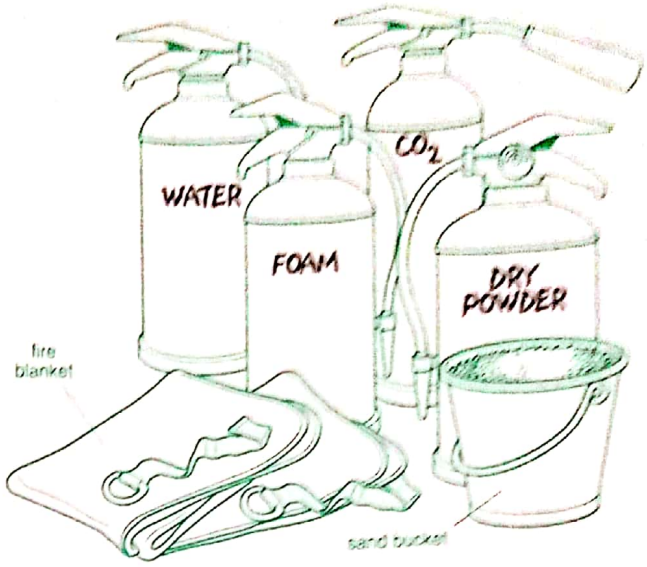


Fig 2.147 Different types of fire extinguishers.

the hazard that may arise as a result of melting insulation exposing live current-carrying wires which could cause electrocution, electric shocks and more fires.

Fire extinguishers

Fire extinguishers are the main firefighting equipment for small fires and the first stages of large fires. They provide a means of controlling large fires until professional firefighters arrive. Fire extinguishers work by releasing substances which push the air away, preventing it from coming into contact with the fire. The reduction in heat by the cooling effect of the water is also important. If a fire is starved of air it stops burning and eventually goes out.

Fire extinguishers commonly contain carbon dioxide gas, foam or powder which is forced out when the extinguisher is activated. Fire blankets and sand buckets are a useful means to put out very small fires in the home or school.

The main methods in use today to extinguish smaller fires are (Figure 2.147):

- fire blankets
- sand buckets
- foam
- carbon dioxide gas (under pressure)
- soda acid (carbon dioxide, water based)
- water (pump)
- dry powder (multi-purpose).

Since the outbreak of fire may be a life and death matter, people working in a building should know the location of the fire extinguishers and know how to operate them. When a fire breaks out it is too late to start looking for the fire extinguisher or wonder how it operates. Table 2.14 summarises how each type of extinguisher is operated effectively.

Bush fires

Bush fires and forest fires happen in Ghana and in other parts of the world. A few are started naturally by lightning but most are started by people. In Ghana, bush fires are commonly started by people who want to use the spread of the fire to trap game. The careless disposal of burning materials, such as smouldering cigarette stubs and firewood are also significant causes of fires, as are carelessly discarded flammable materials including dry garbage, old tyres, plastic materials (polythene products, medicine bottles, upholstery, etc), dry paper and wood.

In villages and other places, thatched buildings and corn barns or silos are vulnerable to fire. Extra care should be taken to avoid contact with fire or fire-laden materials.

Wet blankets and sand are useful for putting out isolated fires in and around homes in towns and villages. Wet tree branches with broad leaves are quite useful for putting out bush fires. In villages and towns where firefighters are not stationed, there is often a group of trained volunteer firefighters who can be brought in to tackle large fires. Ghana National Fire Service personnel can help to establish such groups.

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Table 2.14 Ways to extinguish fires and their effectiveness

Method	How to use it	What it does	Suitability
fire blanket	pull down two tapes attached to the blanket and cover the fire with the blanket; if a person is on fire prevent him from running or fanning the flames; wrap the blanket around him or if he is on the floor roll the blanket around him	it covers the fire and prevents air from getting to it	suitable for burning clothing and small isolated fires which can easily be covered
sand bucket	pour sand over the fire	as above	use on any small fire
foam extinguisher	direct foam to fall lightly on the fire NOT on burning substances	as above	suitable for many fires; do NOT use on electrical fires if the foam is water-based
carbon dioxide extinguisher	direct the stream of carbon dioxide to the base of the fire	displaces air from the fire	safe to use for electrical fires
soda and gas cartridge extinguisher	direct the stream of water and carbon dioxide at the base of the fire	carbon dioxide displaces air from the fire and water cools the material	not suitable for electrical fires because of the water
water extinguisher	with the foot firmly on the footrest, direct the water at the base of the fire	water lowers the temperature and prevents oxygen coming into contact with the fire	suitable for many fires; do NOT use on electrical fires; also not suitable for oil, petrol and paraffin fires because these liquids float on the top of the water and continue to burn
dry powder extinguisher	direct first at the base of the flames and then upwards to the rest of the flame	powder covers the fire, preventing air coming into contact with it	safe for all fires and does not wet the burning material

Corrosive substances

Corrosive substances can destroy living tissue by chemical action; the effects may be observed instantly on the skin of the body if the chemical is concentrated. Corrosive substances attack non-living materials also, for example metallic structures, such as iron bridges and some types of rocks.

Substances such as concentrated aqueous solutions of tetraoxosulphate(VI) acid, H_2SO_4, hydrochloric acid, HCl, hydrogen peroxide, H_2O_2, sodium hydroxide, NaOH and ammonia, NH_3, are very corrosive. In other cases, for example more dilute acids, alkalis and other substances, the process is slow and it takes a long time before the effects are observed.

Both slow and fast corrosive effects are hazardous.

Corrosive substances may be identified by the symbols shown in Figure 2.148.

The first thing to do if a corrosive substance touches or spills on to the body is to wash it well with plenty of water. After this, report the accident to your teacher, the laboratory technician or another adult person who is present. If the corrosive substance has damaged the skin and the effect persists for long, you should report the matter to a doctor or a safety expert.

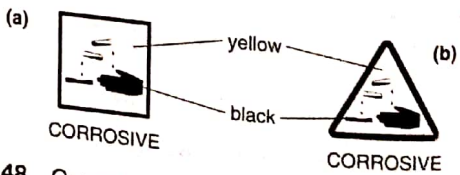


Fig 2.148 Corrosive hazard signs (a) on containers (b) elsewhere, such as the doors of storage cupboards.

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Electric shock

The passage of an electric current through the human body can cause discomfort or injuries; this is described as **electric shock**. The greater the current or voltage, the greater is the severity of the shock.

A simple torch battery, or even a few of them joined together, would not give a significant shock. However, electricity from the mains at 120V or 240V is a serious hazard and a danger to all. Most electric shocks are the result of faulty or defective wiring, particularly where bare wires are exposed. Electrical equipment should be checked regularly if electric shocks are to be avoided. Electric shock may also result from fires and explosions and from other disasters such as earthquakes.

Shocks are unpleasant experiences. Light shocks give no more than a prickling sensation but in severe electric shocks, the heart, muscles, breathing, mental co-ordination and other body functions are impaired and can stop.

If a person suffers an electric shock:

- Switch off the main electric supply immediately and remove the main fuse.
- Do not touch the victim with metal, bare hands or any part of your body, directly or indirectly, until you are sure the electricity is switched off.
- If the victim has to be disconnected from a live wire, use a non-conductor or insulator such as a length of dry wood to move the person.
- Move the person as little as possible. If it is a serious shock, cover the person with extra clothing (thick coat or blanket) for warmth.
- Reassure and comfort the person.
- Administer first aid. Check the strength of the person's pulse and if necessary, give resuscitation (artificial respiration) first aid. See page 317.
- Call for an ambulance or, if not possible, transport the victim carefully to the nearest hospital or clinic.

Food contamination and poisoning

Some foods naturally contain poisonous or toxic substances. The poisonous substances may be in the peel or in the food itself. Examples of such foods are bitter cassava (which contains hydrogen cyanide, HCN), some wild yams (which contain alkaloids) and cocoyam.

When the food is peeled and boiled many poisons are destroyed but some mushrooms are poisonous even if cooked. For the sake of safety, especially for uncommon foods collected from the wild bush or forest, check whether they are edible before eating.

There are millions of micro-organisms (bacteria, mould and yeast spores) in the air. Some are useful, others are harmful. They act on both cooked and uncooked foods but their action is faster on many cooked foods. When cooked food is left in the air for some time it becomes contaminated: for example, mould may form.

Some micro-organisms produce poisons without any noticeable changes in the taste, colour or scent quality of the food. These are the really dangerous micro-organisms which cause food poisoning.

Food poisoning symptoms include fever, stomach ache or cramps, high temperature, diarrhoea, convulsions, headache, nausea, vomiting and dehydration. Food poisoning can lead to organ failures, irreparable damage or even death.

The source of food poisoning may be the kitchen in the home but more often it is traced to restaurant food and foods bought in the street or produced in hot and unsanitary conditions.

Rodents, insects, flies and other animals may carry the poisonous substances that contaminate food. Food left uncovered, especially overnight, in places infested with these animals, is often affected.

Very young people, especially toddlers, and older people, are more likely to be affected by food poisoning. In some countries, food poisoning has become a major health problem because of the greater dependence on food from outside the home. Nevertheless, a home in poor sanitary condition, especially the kitchen, often contains contaminated food, which can result in poisoning.

Undercooked or improperly preserved meat, poultry, eggs and dairy products such as milk, are some of the main causes of food poisoning, for example by salmonella bacteria. Keeping cooked food in a warm place for hours creates a fertile ground for the multiplication of toxic bacteria and can lead to food

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poisoning. Some common Ghanaian foods that are very easily contaminated under such conditions are kontomire, fish, meat and bean foods.

Harmful radiation (X-rays) and poisonous chemicals

The main source of X-rays is X-ray machines in hospitals. Over-exposure to X-rays causes cancer, chromosome damage and bone marrow damage. Radioactive sources such as nuclear reactor leaks and accidents and nuclear tests produce harmful radiation that causes many diseases, including cancer and gene damage.

Scientists have found that exposing some plastics such as PVC to extreme cold and heat results in the formation of hydrogen chloride (HCl) and dioxins. Dioxins are very stable organic molecules that take a long time to break down in the environment. They get inhaled or into water and eventually end up in humans where they may cause diseases such as cancer, birth defects and skin diseases.

Safe storage of hazardous substances and safety or hazard symbols

Hazardous substances should be clearly labelled and given special *care* and *storage*; very hazardous ones should be kept under lock and key or in special cabinets or shelves in laboratories, the home or the workplace.

All hazardous substances must be labelled with their names and the internationally recognised hazard symbols so that people give them the special care and attention necessary. The hazard symbols are shown in Appendix V. You should study this carefully. Notice, for example, the different colours used for the different types of symbol. You should be able to recognise each sign and know what it means.

When storing hazardous substances, care should be taken not to store together substances which easily react with each other: for example, concentrated ammonia should not be stored with concentrated hydrochloric acid. Such chemicals should be stored in different cabinets or on shelves far apart.

Summary of simple safety measures

Many measures contribute to safety. Some have been mentioned in this book; other books can be referred to for more information. Here are just a few of the things that can be done to improve safety at home, at school and in the workplace:

- Install a First Aid box, even if it is modest.
- Wear protective goggles when engaged in hazardous experiments and activities.
- Keep manuals and instruction leaflets that advise on the use, maintenance and potential hazards associated with equipment and appliances.
- Wear protective clothing for example laboratory coats, welding shields, hard boots or shoes and helmets when working with hazardous substances or in hazardous conditions such as high electric tension lines, on scaffolding, inside buildings being constructed and on roofs.
- Substances which, when mixed, can cause fires, violent explosions, reactions or dangerous and undesirable effects should be stored well away from each other.
- Know where safety and life-saving devices are located and how they are operated.
- Keep the area in which you work clean and tidy.
- Post hazard warning signs or simply-worded advice any place where it is necessary.
- Don't look directly at a dazzling or blinding light, for example the Sun or a welding arc or flash.
- Enforce safety and hazard rules both at home and at the workplace.
- Post laws, regulations and codes of conduct in simple language at workplaces and elsewhere.
- Store chemicals below the shoulder height of the shortest user.
- Always look out for expiry dates and do not buy food that is beyond its expiry date.
- Use electric circuit breakers and stabilisers to protect life and property.
- Carry out regular safety checks at workplaces.
- Treat hot things with care – they are hazardous.
- Read and follow the instructions on medication.

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ACTIVITY 4 Identifying occupational hazards and their effects

1 Each student should provide the following information:
   a) two occupations, at least one from within his or her own home
   b) any hazards associated with each occupation
   c) the effects of and/or any disease caused, by each hazard.

Note: Each job should be explained, if need be, to throw more light on its nature, for example conservancy labourer, psychiatric nurse or doctor, chemistry teacher, truck driver, etc.

2 Put together the data from all the students. Tabulate it in three vertical columns under the headings: 'Job/ profession', 'Hazard(s)', 'Effect/disease'.

3 Discuss the data and decide on the:
   a) most hazardous job
   b) least hazardous job
   c) avoidable hazards
   d) most dangerous diseases or effects
   e) any other important finding(s).

4 Prepare a poster, listing the ten most hazardous jobs, for display in the classroom.

It is important for all of us to examine our attitudes to hazards. Avoiding the effects of hazards is a personal responsibility; every individual has a role to play in keeping ourselves and our societies and communities safe. Self-inflicted hazards, for example disregard for known safety rules, tobacco-smoking, alcoholism and careless driving put people and communities at risk. Conscious efforts should be made to avoid such behaviour. Public education and the reduction in illiteracy, especially in developing communities, help to promote public safety and the avoidance of hazards.

Activity 5 Identifying hazards and their labels

1 Collect as many chemical or substance containers which carry hazard labels, as possible. Examples are containers for oils, paints, laboratory chemicals, medicines, foods, cleaners, etc.

2 Examine each container to find out:
   a) the chemical or substance contained
   b) the hazard symbol – sketch it
   c) the meaning of the label and any comments.

3 Note down your findings in a table:

Substance	Sketch of hazard symbol	Meaning of hazard	Comments

ACTIVITY 6 Demonstrating the operation and construction of a fire extinguisher

1 Your teacher will demonstrate the following methods of extinguishing fires:
   a) sand bucket
   b) fire blanket
   c) carbon dioxide fire extinguisher.

Note: If fire extinguishers are not available, invite a firefighting officer from outside the school to help with the equipment and demonstration.

2 a) Examine the carbon dioxide fire extinguisher.
   b) With ideas gathered from this examination, construct a simple home carbon dioxide fire extinguisher.

Hint: Collect a cylindrical container, local materials which can react to give carbon dioxide gas. Build in a plunger.

3 a) Using a suitable container and sand, build a sand bucket fire extinguisher.
   b) Outline how you would construct it.
   c) Create a small fire outdoors and use the sand bucket to put it out.

4 a) Improvise a fire blanket and put out a small fire.
   b) Outline the steps in your improvisation.



Fig 2.149 Hotel fire extinguisher.

Common hazards in the community

Natural and man-made hazards have always been present in human communities. Industrialisation has increased the number of chemicals, machines and objects, in communities. These have, in turn, increased the number of hazardous situations. An insanitary condition in any community is a potential hazard, since it leads to the outbreak of diseases and the spread of parasites and pests, such as rats.

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Traffic problems, such as careless driving or driving while drunk or tired, cause accidents that can result in injury or death. In big towns and cities, traffic congestion leads to stress and an increase in toxic emissions (carbon monoxide, sulphur(IV) oxide) that eventually produce acid rain and cause disease.

Pollution contaminates the environment with materials that negatively affect people's health and quality of life. Pollution can contaminate water, air and soil; these all affect human and animal life and the environment. Pollution is the cause of many diseases and degradation of the environment. Chemicals and waste products, such as pesticides (for example, DDT), weed-killers, herbicides, dynamite (illegally used in fishing), agricultural fertilisers and cyanide spills (from gold mining), cause destruction of vegetation and pollution of ecosystems. Many of the negative effects of pollutants have been discussed in other parts of this book.

Public health

Public health is the health care provided to all people and is paid for by the government. Public health activities are expected to:

- prevent human disease, injury and disabilities, for example promoting a clean environment to prevent malaria and cholera
- protect people from health and environmental hazards, for example immunisation
- promote human activities that promote good physical and mental health, for example physical exercise and eating of healthy foods
- educate people on good health, for example about sanitation
- inform people of the health services and facilities available, for example clinics and hospitals.

Public heath services in Ghana are included in the activities of the Ministry of Health. Public health workers in Ghana include the brown-uniformed government nurses who move from community to community or work in clinics to provide general health services and health services related to the problems of a particular community. Recently, non-governmental organisations have begun to provide free health care services to people in poorer communities, which may be considered a public health service

The role of health service organisations

Every country has health service organisations. Many countries, including Ghana, have a government agency, such as a Ministry of Health, that is responsible for providing and managing health care. Health care may be paid for, free or guaranteed under various insurance schemes. Ghana operates under a National Health Insurance Scheme (NHIS). International organisations, under the auspices of civil society and the United Nations, also exist; they provide health and health-related services such as funding, research and statistics on human health and food production.

Details of health education and other services that may be provided by public health institutions and international organisations are discussed below. Their work includes the proper management of homes and the efficient and proper planning of towns and villages to provide a healthy environment.

International health organisations

The **International Red Cross Society** is a voluntary organisation with its headquarters in Geneva. It sends teams to assist in times of war, provides food, shelter and clothing for refugees and gives training in basic First Aid. It is always looking for volunteers; working for it is an excellent way of helping society.

The **World Health Organization (WHO)** was established in 1948 to further international co-operation in 'promoting the highest possible level of health for all people'. Its headquarters are also in Geneva and it has six regional offices across the world. Its African headquarters are in Alexandria, in Egypt. The work of WHO falls into three main categories:

1 **Co-ordination** – WHO acts as a clearing house for health information and research services. Quarantine and vaccination measures are standardised internationally to make travel between countries easier. WHO organises the distribution of information on nutrition, vaccines, drug addiction control and radiation hazards.
2 **Disease control** – WHO supports the control of epidemic diseases by promoting vaccination programmes, pure water supplies and health education. It has achieved notable successes against

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smallpox (now eradicated in the world), tuberculosis, malaria and certain sexually-transmitted diseases.

3 **Health administration** – WHO makes major contributions towards improving public health administration by giving technical advice and aid in planning. It also conducts field surveys, helps to set up health centres and contributes towards the education of doctors and nurses.

The **Food and Agriculture Organization (FAO)** is another United Nations agency, with its headquarters in Rome. It gives international support to national programmes for improving efficiency in agriculture, forestry and fisheries. It carries out a continuous review of world food programmes, which contribute towards the health of nations by improving the food supply. Its African headquarters is in Accra, Ghana.

The **United Nations International Children's Emergency Fund (UNICEF)**, another United Nations organisation, has its headquarters in London. The funds collected by UNICEF meet the needs of children throughout the world. The aid is particularly important where children are deprived through war or famine. These occurred together in Ethiopia in 1984 and caused massive starvation and death. In Ghana, UNICEF is supporting a number of activities to improve the life of children in rural areas.

Collection and disposal of domestic refuse

Waste from houses, industry and other sources must be collected and disposed of to keep the environment healthy and safe to live in. Local authorities organise the collection of refuse from dustbins and other places in special, covered, refuse-collection lorries (Figure 2.150). The refuse can either be taken to deep pits, where it is buried or to incinerators where it is sorted and the flammable content burnt. When refuse tips are full, bulldozers are used to pack the material tightly together and it is then left to decompose.

If landfill sites are eventually covered with topsoil they can be grassed over and used as recreational areas, for growing crops or for animal grazing. The privatisation of refuse collection services may improve their speed and efficiency.





Fig 2.150 (a) a dustbin with lid, (b) a refuse collection lorry.

Uses of waste

Waste can become a source of wealth where appropriate skills and technology are available. The ways in which waste can be used to generate income include:

- recycling
- recovering waste for reuse
- turning domestic waste into manure
- channelling treated waste water for agricultural use
- treating biomass to become biogas for energy
- harnessing solar energy to power communication gadgets and for heating and lighting
- using maize husks and fruit and plant fibre to make door mats and other products.

Recycling

In Ghana, attempts have been made to convert broken-down vehicles and other scrap metal into iron rods for

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construction purposes. At Wahome and Metal Industry in Tema, tonnes of scrap are recycled daily into iron rods and roofing materials.

In many developed countries, waste paper is recycled into other paper products such as toilet rolls, newspapers, napkins, paper bags and wrappings. A small percentage of Ghana's waste paper is recycled by Paper Products Ltd.

Improved technology should enable the recycling of sawdust, which is burnt in most saw mills, into insulation for construction and other purposes. The Council for Scientific and Industrial Research has succeeded in using sawdust to make doors and tiles for ceilings.

The recycling of aluminium scraps to construct cooking pots, bowls and serving trays has reduced the cost of equipping our educational institutions.

In advanced countries, such as Japan, polythene bags and other plastic materials are recycled into fuel to power machines.

ACTIVITY 7 Recycling

1 List the types of materials in your area that can be recycled. Suggest products that could come from them and their possible uses.

2 Write a report educating the public on the need to recycle. Emphasise the role of recycling in environmental sanitation, socio-economic growth and broadening the scientific and technological base of the nation.

Recycling organic waste

Agriculture provides several sources of manure. Poultry droppings, waste from cattle and waste from harvested crops can all be decomposed to produce organic fertiliser.

Unwanted market produce is frequently left to decompose in the marketplace, polluting the streets and air. This, and waste from farm products, could be converted to manure and used to improve the fertility of soils that are, all too often, rendered infertile by over-use and leaching.

Biomass digesters, such as the one in Appolonia, near Tema, Ghana, turn animal and human faeces into biogas to supply energy to the village.

Public health and sanitation

Poor sanitation has long been a threat to human life. Many diseases, including cholera, diarrhoea, dysentery, bilharzia, typhoid, malaria, poliomyelitis (polio) and ascariasis (worms) are commonly associated with poor sanitation.

Poor disposal of refuse, air and water pollution and poor ventilation are among some of the factors that lead to poor health. It is unhygienic and a health hazard to urinate or defecate into or near sources of drinking water such as rivers, lakes and streams. It is also risky to bathe in water that may have been infected with the causative agent of bilharzia.

People must be made aware of habits and activities that promote poor sanitation and lead to pollution of the environment. Practising personal hygiene is part of good sanitation and must be encouraged.

Many diseases attributed to witchcraft in some societies are actually the result of poor sanitation. This is purely a matter of illiteracy and ignorance. Such societies need to be educated on the true causes of these diseases. Steps must be taken to improve sanitation and establish a good standard of health in every community. These include:

- proper siting of refuse dumps
- provision of waste bins
- cleaning and de-silting of gutters
- clearing bushes around houses
- proper house planning to improve ventilation
- provision of trees and flowers
- regular cleaning of homes and public toilets
- efficient town and village planning systems
- provision of a clean water supply
- maintenance of clean roads.

Proper siting of refuse dumps

'Refuse' refers to domestic waste matter. This includes empty tins, plastic bags, fallen leaves, plastic containers, empty cans, waste paper, broken pots and plates, bottles organic kitchen waste and dust and dirt.

Refuse must not be left scattered around houses. There must be a public refuse dump sited outside every village, town and city, away from where people live and not located where the prevailing wind can transmit bad smells. It should preferably be in a depression or a large hole. Rubbish bins should be provided in villages, towns and cities and these should be regularly emptied and the rubbish disposed of safely.

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Cleaning and de-silting gutters

Open gutters must be swept daily and scrubbed regularly. Rubbish and sediments in the gutter should be removed. This is known as **de-silting** the gutter.

These activities help to prevent the occurrence of standing water which may give off bad odours. A disinfectant solution should be poured into the gutters from time to time. This prevents bad smells in and around the house and deters flies. Any cracks in the gutters should be mended immediately. This prevents water leaking into the foundations of the building where it may weaken and damage the structure.

Proper house planning to improve ventilation

Ventilation means allowing fresh air into a room, office or any living space. This may be achieved either by natural and artificial means.

Natural ventilation is achieved by planning houses in such a way that there is a slow movement of air from outside through the rooms. Each room must have an adequate number of windows, which should be large and raised above ground level. The windows of a room should face each other, so that fresh air can move through the room depending on the direction of the wind. This is known as cross-ventilation. Glass louvre shutters allow light into the room even if they are closed. They also prevent too much sunlight from entering the room which may overheat it.

Air vents should be sited in the ceilings and high on the walls. These holes allow stale, warm, humid air to escape from the room and be replaced by fresh, cool air flowing into the room from lower down (Figures 2.151 and 2.152).

Trees planted close to houses provide some shade, while wide verandahs provide shade and coolness,

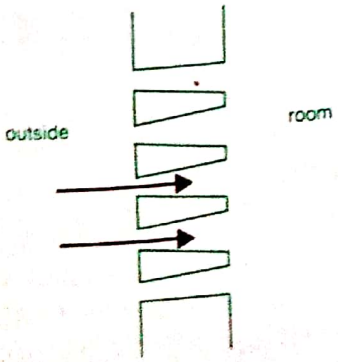


Fig 2.151 Ventilation bricks.

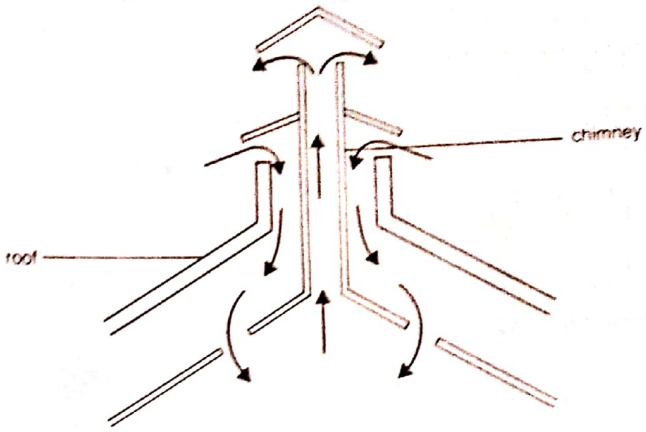


Fig 2.152 A roof vent.

aiding good ventilation. If houses are sited on hillsides, fresh breezes provide natural ventilation.

Artificial ventilation may be achieved by electric fans. These keep the air moving and circulating. Air conditioning units remove heat and moisture from the air.

Ventilation is important because it replaces warm, humid, stale, stagnant air with fresh, dry air. This increases evaporation of sweat from bodies and prevents headache and drowsiness due to overheating and high levels of carbon dioxide. It also reduces droplet infection by bacteria and viruses and prevents pests such as termites, cockroaches, bed bugs and silverfish from invading rooms. Other factors that make a well-planned house are illustrated in Figure 2.153.

Provision of trees and flowers

Trees such as whistling pine, cassia and neem tree should be planted around and near houses. They reduce reflected glare and provide shade, making rooms cool and refreshing. Trees also serve as **shelter belts** and help prevent the destruction of houses in strong winds.

Cleaning of home and public toilets

General cleaning includes:

- Sweeping the floor with a broom.
- Removing cobwebs from the walls, ceiling and windows.
- Scrubbing the floor regularly with soapy water and sprinkling with disinfectant.
- Leaving doors and windows open for a time to ventilate and dry the floor quickly.

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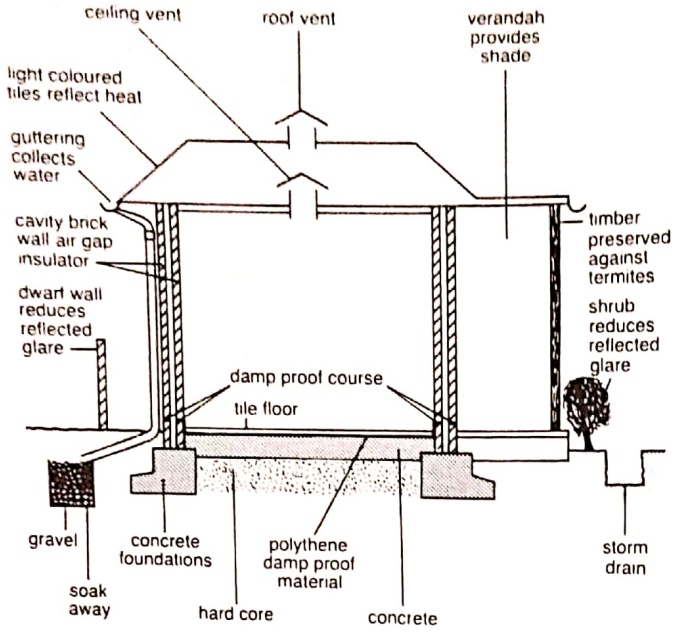


Fig 2.153 A well-planned house.

The various types of toilets used in Ghana are bucket latrines, pit latrines and ventilated improved pit latrines (in towns and villages) and water closets (in towns and cities).

To clean bucket latrines the bucket should be removed and emptied every day and the faeces carried away and buried by conservancy workers. The empty bucket must be washed thoroughly with soapy water, scrubbed and dried before being put back into place. Sawdust, wood ash or a suitable disinfectant should be put into the bucket from time to time to reduce bad smells and deter flies. The toilet seat and cover should also be scrubbed.

In pit latrines, the seat and rim of the toilet should regularly be scrubbed with soapy water. Quicklime (kaalo) should be placed in the latrine from time to time to prevent the bad odours that attract flies. Community pits should be deep and sited well away from houses and sources of drinking water. Water should be poured into pits from time to time to speed up the decay of the faeces.

Water closets must be flushed immediately after use to prevent bad smells and exposure to harmful bacteria. Toilet paper (tissue) should always be used and put in the bowl after use. Scouring powder, soapy water and a toilet brush must be used to scrub the bowl inside and outside. The toilet brush should be kept clean and the bowl of the water closet should be white-washed.

Clean roads

Every village, town or city relies on roads for access. The roads must be wide enough to allow the free movement of vehicles and pedestrians. Bushes along roadsides must be kept low. In Ghana, this is carried out by the Ghana Highway Authority. Tall bushes along roadsides harbour snakes that may bite unsuspecting pedestrians. Tall bushes may also reduce visibility and cause accidents.

Roads passing through villages, towns or cities must be kept clean by regular sweeping. City councils employ people specifically for this purpose in towns and cities. Householders alongside roads should be encouraged to sweep the road in front of their houses. Regular clean-up campaigns should be organised for general cleaning of roads and gutters. In cities and towns, bright street lights must be installed at approved intervals to improve visibility at night.

ACTIVITY 8 Studying sanitation in your locality

1. Use a large sheet of paper, about 30 cm square, to make a map of your locality.
2. Mark any hilly ground on your paper.
3. Mark where houses are located. Are the numbers of houses at each site well spaced or crowded?
4. Observe how houses are ventilated. Are the houses naturally or artificially ventilated? How many houses use either or both of these means of ventilation?
5. Locate and mark on your map the place for refuse disposal, sources of drinking water and public toilets. Are these sited correctly? Are the toilets kept clean? Are waste bins provided? Is refuse regularly removed by lorry?
6. Observe the drainage system, road network and street lighting. Is each adequate and correctly sited? Are roads and gutters kept clean?
7. Make a poster illustrating the dangers to health of poor sanitation.
8. Organise a clean-up campaign. Go out as a group and do something positive to improve the sanitation in your locality.

Town planning

In Ghana, many towns and villages have grown over the years without any particular plan. Houses, schools, hospitals and clinics, water works, sewage works and refuse dumps have been built and positioned haphazardly, often leading to difficult, unsanitary and unattractive conditions.

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However, there are towns, such as Tema, an industrial town in the south of Ghana, Sunyani, the capital of Brong Ahafo region and Wa, the capital of the Upper West region, which have been carefully planned and positioned; these are pleasant to live in and function efficiently.

Town planning is the guidance of the growth and change of urban areas, at the same time as fulfilling social and economic objectives. The main factors to be considered are:

- the provision of houses, business and industries that function well together
- an efficient system of transport within the town and to the surrounding area
- the provision of adequate, safe and economical water and power supplies
- the provision of safe and effective refuse and human waste disposal systems
- the provision of schools, markets, hospitals and other community services
- the development of the area to the highest possible standard, making the best use of space, sunlight, etc.

The effects of urbanisation on the environment

The increase in population brought about by the development of urban areas gives rise to an increase in demand for efficient water and power systems as well as refuse and human waste disposal systems. The increase in traffic gives rise to an increase in both air and noise pollution. The increased use of the land causes erosion and encroachment on valuable farming land. All these, as well as the provision of basic requirements such as food and clothing have to be taken into consideration in town planning.

Self check

For questions 1 to 15, choose the letter that refers to the correct option.

1 Which of the following steps should you take in giving first aid to a person who falls in a slippery bathroom and faints?
- A Check for cuts, bandage them and send the person to hospital
- B Put the person on their side, provide enough ventilation and call for help
- C Wash the person's face with cold water and look for a fan to blow air over the person
- D Run and call the nearest nurse to give some drugs

2 The best way to put out a fire from a gas source is to
- A cover it with a blanket
- B pour water on it
- C close the tap to the gas supply
- D switch off the electric light

3 Which of the following is NOT a natural hazard?
- A earthquakes
- B asbestos dust
- C disease
- D forest fires

4 Which of the following statements corrosive substances is NOT true?
- A corrosive substances can destroy the skin
- B concentrated tetraoxosulphate(vi) acid is corrosive
- C corrosive substances dissolve glass
- D containers of corrosive substances should be labelled with the appropriate hazard symbol

5 Which of these fires should be tackled with water?
- I someone throws a firecracker on to dry grass outside your house
- II fire is created by water coming into contact with calcium carbide in the market
- III the oil in a frying pan catches fire
- IV heavy smoke issues from the TV in your living room.

- A II only
- B I only
- C I, II, III, IV
- D I, III

6 Which of these methods would you use to put out the fire if someone's clothing catches fire in the kitchen?
- A sand bucket
- B fire blanket
- C add cold oil
- D carbon dioxide gas extinguisher

7 A hazard warning symbol shows a thick black cross, on a yellow background, in a square shape. This indicates that:
- I the substance in the container is harmful
- II the contents of the cupboard are dangerous
- III special precautions should be taken when handling the contents
- IV this is a First Aid item.

- A IV only
- B I, III
- C II, IV
- D I only

8 Removing rubbish and sediments from gutters is called
- A filling
- B opening
- C desilting
- D mending

9 The essential elements in town planning are:
- I provision of schools
- II human waste disposal system
- III water supply
- IV provision of zoos.

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A I and II only
B II and III only
C II, III and IV only
D I, II and III only

10 Which of the following ingredients are necessary to create and sustain a fire?
I Heat
II Oxygen
III Fuel
A I and II only
B I only II only
C II only and III only
D I, II and III

11 Which of the following can start a fire with a combustible material in air?
I Electric current
II Lightning
III Intense light radiation
IV Match
A IV only
B IV and II only
C IV, III, II and I
D I, II and III

12 Food poisoning is caused by:
A Some bacteria
B Bushfire
C Freezing temperatures
D All mushrooms

13 Traffic problems, such as jams in big cities, can cause:
I pollution of the air
II acid rain
III typhoons
A II only
B III only
C I and II only
D I and III only

14 List the hazards that can be prevented when a scientist uses protective:
a) goggles
b) boots
c) apron
d) gloves
e) mask.

15 Name some occupations in Ghana that require protective clothing.

16 List three hazardous substances, situations or conditions. Next to each one state the best way to:
a) deal with the hazard if it occurs
b) avoid the hazard.

17 Briefly describe the immediate action you would take to avoid or recover from these occurrences or situations:
a) climbing steps, a friend trips and falls, bleeding from a leg injury
b) a kerosene fire is caused by a lit kerosene lamp
c) petrol is smelt when you enter a room
d) your friend's hand is cut by a piece of blade.

18 a) Describe four possible hazards faced by lawn workers.
b) State two precautions which could be taken to avoid each hazard.

19 a) What type of hazard does the symbol below warn us about?
b) From its shape, state where you might find it.
c) What colours would be used in the symbol?
d) What word or words might be below the symbol?
e) Suggest two substances it might refer to.



Fig 2.154 Hazard symbol

14 Which of the following hazardous gaseous products can be produced when some plastics such as PVC are burnt at refuse dumps?
A Dioxins and hydrogen chloride gas
B Water vapour
C Freshwater
D Salty water

15 Hospital waste is a special type of waste that is burnt in kilns in some hospitals to:
A save the lives of patients in the hospital
B save energy used in the hospital
C prevent contact with humans and animals to transmit diseases
D recycle the disposable metal waste

16 a) What should you use to put out a bush fire?
b) What are the dangers from a burning foam mattress?

17 a) A water heater is left in a plastic bucket of water on a wooden table. What is the possible result of this carelessness?
b) What fire extinguishers would you recommend for putting out a fire caused in this situation?

18 Identify five different ways of putting out a fire. For each one, say how it stops the fire.

19 What are the main hazards in using the following in the home:
a) a candle
b) an electric iron
c) a gas cooker
d) an electric kettle
e) an air conditioner
f) a television.

20 What is the correct first aid treatment for:
a) a cut
b) a burn
c) a sprain

20 In your own words, describe briefly, an accident or hazard you have been involved in or exposed to. Include how you were helped out of the incident.

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21 State five functions of the World Health Organization.

22 Explain how collection and disposal of domestic refuse can be improved.

23 Explain how waste can be a source of wealth.

24 a) What is ventilation?
b) State two factors that must be considered to ensure proper ventilation when building a house.
c) Give three reasons why proper ventilation is necessary for humans

25 State the factors that must be considered in order to plan a town efficiently.

26 State the (a) hazard and (b) likely consequence of:
a) Sitting very close to a TV set
b) Loose electric wires and exposed wire connections
c) Keeping petrol in the home
d) Throwing smothering/glowing cigarette stub into a forest
e) Walking at a stone quarry site without wearing a helmet
f) Turning a gas cooker or Bunsen burner on before striking a match
g) Eating food left overnight without cover
h) Exposure to dust at an asbestos roofing sheet factory
i) Inability to operate a fire extinguisher

27 a) What is meant by national Public Health Services?
b) State three services that Public Health workers provide in your community.
c) Describe briefly how any one of the services stated in (b) is provided in your community.

28 State one common hazard in your community that is caused by:
a) a pest
b) insanitary conditions
c) a pollutant
Give one specific example of each hazard stated in (a) above that may exist in some communities.

29 Which of the following hazard signs would appear on:



Fig 2.155 All four hazard signs

a) a chemical that is dangerous for the environment
b) a liquid that is inflammable
c) a solid that corrosive
d) a toxic chemical on a shelf in a shop.

30 Discuss briefly whether a hazard sign alone on an item being sold in a shop gives sufficient health information.

31 a) List two causes of electric shock accidents in the home.
b) Describe briefly the fist aid you would give to an electric shock victim.
c) In each case of the cause of electric shocks given in (a) describe briefly how you would prevent the situation that causes the accident.

32 Five appliances or devices or situations in the home have been listed in the table below. Fill in the accidents that can be caused by each appliance and the way the accident can be avoided.

Appliance	Accident that can be caused	Way to avoid accident
1. Electric water heater		
2. Liquefied petroleum gas container		
3. Unlabelled chemical or medicine container		
4. Bare electric wires		
5. Sharp and rusty nail on cupboard		

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Year 3

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1 Metals and non-metals

Learning objectives

After studying this unit, you should be able to:

1 classify materials into metals, semi-metals and non-metals and relate them to their physical and chemical properties
2 relate the properties of metals, non-metals and semi-metals to their uses in the home and other places
3 explain what alloys are, their properties and uses.

Background information

In simple terms metals, semi-metals and non-metals are all part of the large diversity of matter. Most exist combined in their compounds in the earth as ores and can be extracted as pure metal before use. Each has physical and chemical properties that distinguish it from the other. Their uses are based on their physical and chemical properties. Metals, semi-metals and non-metals and their numerous products have served humans for thousands of years sustaining and improving our quality of life. Semi-metals such as silicon are used to make microchips. This in turn is a critical component of most modern electronic equipment. Alloys are more useful than the pure metals. See the next unit for descriptions of the extraction of aluminium and gold metals.

Metals, semi-metals and non-metals

Elements may be classified as metals and non-metals on the basis of their chemical and physical properties. A small number of elements have a mixture of properties, some typical of metals and others typical of non-metals. These are referred to as semi-metals or metalloids. Metals, however, combine chemically with non-metals to form compounds such as NaCl and CuO.

Elements which are **metals** are found on the left-hand side and middle of the periodic table; elements which are **non-metals** are found on the right-hand side. **Semi-metals** occupy the region between metals and non-metals (see page 24, figure 1.2.3).

ACTIVITY 1 To locate the relative positions of some metals, non-metals and semi-metals in the periodic table

1 Look up the following elements in the periodic table (Appendix III). From their positions decide whether they are metals, non-metals or semi-metals:

potassium (K), zirconium (Zr), bromine (Br), xenon (Xe), titanium (Ti), gallium (Ga), carbon (C), silicon (Si), lead (Pb), barium (Ba), germanium (Ge), iodine (I), molybdenum (Mo), bismuth (Bi), selenium (Se), Boron (B), zinc (Zn), mercury (Hg).

2 Arrange the elements into three groups under the headings: 'Metals', 'Non-metals' and 'Semi-metals'.
3 Explain why plastic, wood and glass are not metals or non-metals.

ACTIVITY 2 To collect objects made from various elements and to classify them as metals or non-metals

1 Collect as many objects made from different elements as you can. If you are unable to remove an object from where it is, note from what element it is made and what it is or does.
2 Classify the objects you have collected or noted into 'Objects made from metals' and 'Objects made from non-metals'.

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Properties of metals, semi-metals and non-metals

Physical properties of metals and non-metals

The properties of *metallic* elements are very different from those of non-metallic elements. In general, metals are **ductile** (they can be drawn into wires), and malleable (they can be beaten or hammered into different shapes). Metals are also good conductors of heat and electricity and are therefore used for electric wiring and to make car radiators, cooking pots and various other articles that conduct heat. In general, metals have a high lustre, which refers to the way light interacts with the metal surface, giving it a shiny appearance.

Many metals and their alloys produce sound when struck. This property is called 'sonority' and it is used in musical instruments such as bells and cymbals to give various sounds.

The ability of materials to bear weights or forces without tearing apart is known as 'tensile strength'. Metals such as iron and aluminium and their alloys have high tensile strength. This is why they are used in structures such as bridges, bodies of vehicles and aeroplane bodies as they can carry heavy loads without breaking down.

The physical properties of aluminium and gold are typical of metals (Table 3.1).

Table 3.1 Physical properties of aluminium and gold

Property	Aluminium	Gold
melting point/°C	660	1064
boiling point/°C	2520	2707
density/g cm^{-3}	2.7	19.3

Metals have a wide range of densities – that is, how heavy they are. In units of g cm^{-3}: from the lightest lithium (0.54), magnesium (1.74) and aluminium (2.7); to iron (7.9), mercury (13.6), gold and tungsten (19.3), and iridium (22.4) the heaviest.

Many metals have high melting points, for example, iron (1535°C), Nickel (1453°C) and silver (962°C). Tungsten has the highest melting point (3410°C). Few have low melting points such as sodium (98°C) and magnesium (649°C). Mercury has the lowest (−39°C) and exists as a liquid.

Some *non-metallic* elements are gases e.g. hydrogen and oxygen; others are liquids or solids. Non-metals (except graphite) are poor conductors of heat and electricity. The solid non-metals are often called **insulators**.

Table 3.2 summarises the differences in the physical properties of metals and non-metals.

Table 3.2 Differences in the physical properties of metals and non-metals

Property	Metals	Non-metals
melting point	usually high	usually low
boiling point	usually high	usually low
density	usually high	low
conducting heat	good	poor
conducting electricity	good	usually poor, carbon (graphite) is an exception

Chemical properties of metals

Many metals undergo a wide range of chemical reactions. Atoms of metals have fewer electrons in their outermost shells than do non-metals. These fewer electrons can easily be lost to other atoms to form new compounds. The chemical properties of aluminium and iron are typical of metals. They produce positively charged ions (cations), Fe^{2+}, Fe^{3+} and Al^{3+}.

Reactive metals such as iron and aluminium react with oxygen in the air to form oxides that tarnish their surfaces. We will discuss this further in Unit 3 of this section. They also react with water to form oxides or hydroxides, and with dilute acids to form salts and hydrogen gas. A few metals, including aluminium, zinc and lead, react with both acids and alkali and are described as **amphoteric** metals. In Table 3.3 the main reactions of some metals with oxygen, water, dilute acids and alkalis are summarised.

Unreactive metals, such as silver and gold, are not affected by air, water, dilute acids or alkalis. Gold, however, dissolves in aqua regia, a mixture of three parts concentrated hydrochloric acid, HCl, and one part concentrated trioxonitrate(v) acid, HNO_3.

Chemical properties of non-metals

Non-metals are generally unreactive. Many do not react with dilute acids and when they react with oxygen from the air, dilute alkalis and water, they do so at higher than normal temperatures. Some of the few reactions with importance are briefly discussed here.

Reactions with oxygen from the air

Carbon in any form reacts, when heated, with oxygen from the air to give carbon dioxide (carbon(IV) oxide)

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Table 3.3 Summary of the main reactions of metals

Metal	Reaction with oxygen from the air	Reaction with water	Reaction with dilute acids	Reaction with dilute alkalis
Na	$2Na(s) + \frac{1}{2}O_2(g) \rightarrow Na_2O(s)$ (white solid)	$Na(s) + H_2O(l) \rightarrow NaOH(aq) + \frac{1}{2}H_2(g)$ violent reaction	explosive reaction to give hydrogen gas	no reaction
Ca	$Ca(s) + \frac{1}{2}O_2(g) \rightarrow CaO(s)$ (white solid) slow reaction	$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$ brisk reaction	$Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$ vigorous reaction	no reaction
Mg	$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$ (white solid) slow reaction – gives dazzling bright light when heated to ignite	$Mg(s) + H_2O(l) \rightarrow MgO(s) + H_2(g)$ reacts only with boiling water or steam	$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$ vigorous reaction	no reaction
Al	$2Al(s) + \frac{3}{2}O_2(g) \rightarrow Al_2O_3(s)$ white oxide prevents further reaction	very slow reaction	$Al(s) + 3HCl(aq) \rightarrow AlCl_3(aq) + \frac{3}{2}H_2(g)$	$2Al(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2NaAl(OH)_4(aq) + 3H_2(g)$
Zn	$Zn(s) + \frac{1}{2}O_2(g) \rightarrow ZnO(s)$ (white solid) slow reaction	very slow reaction	$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$	$Zn(s) + 2NaOH(aq) + 2H_2O(l) \rightarrow Na_2Zn(OH)_4(aq) + H_2(g)$
Fe	$2Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s)$ (brown solid)	$3Fe(s) + 4H_2O(g) \rightarrow Fe_3O_4(s) + 4H_2(g)$ reacts with steam	$Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$	no reaction
Cu	doesn't react with dry air but in moist air forms a green coating called verdigris or black solid CuO when heated	no reaction	no reaction	no reaction
Ag	no reaction	no reaction	no reaction	no reaction

or carbon monoxide (carbon(II) oxide) and heat. By giving out heat carbon serves as a fuel. In a good supply of air the equation is:

$$C(s) + O_2(g) \xrightarrow{\text{heat}} CO_2(g) + \text{heat}$$

In a limited supply of air the equation is:

$$C(s) + \frac{1}{2}O_2(g) \xrightarrow{\text{heat}} CO(g) + \text{heat}$$

When sulphur is heated in air a pungent smelling gas, sulphur dioxide (sulphur(IV) oxide) SO_2, is formed; the equation is:

$$S(s) + O_2(g) \xrightarrow{\text{heat}} SO_2(g)$$

Reactions with water and steam

Chlorine gas dissolves slightly in water to give a solution which is an antiseptic and bleaches; the equation is:

$$Cl_2(g) + H_2O(l) \rightarrow HCl(aq) + HOCl(aq)$$

The oxochlorate(I) acid, HOCl, is responsible for the bleaching effect. It bleaches by oxidising the coloured material thereby removing the colour and turning it white.

Steam reacts with red-hot coke (carbon) to produce a mixture of hydrogen and carbon monoxide gases called water gas. Water gas is used industrially for heating; the equation is:

$$C(s) + H_2O(g) \xrightarrow{\text{redheat}} CO(g) + H_2(g)$$

Reactions with alkalis

Chlorine gas reacts with dilute sodium hydroxide to give a mixture of salts, sodium chloride and sodium oxochlorate(I). The equation is:

$$Cl_2(g) + NaOH(aq) \rightarrow NaCl(aq) + NaOCl(aq) + H_2O(l)$$

Sodium oxochlorate(I) (sodium hypochlorite) is a mild bleaching agent which, like oxochlorate(I) acid, bleaches by oxidation.

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Properties of semi-metals

Semi-metals (sometimes called metalloids) are elements whose properties are intermediate between metals and non-metals. Boron, silicon, germanium, tellurium and arsenic are examples of semi-metals. In the periodic table, semi-metals are found on the right squeezed between metals and non-metals (Appendix III). They exhibit a mixture of metallic and non-metallic properties.

Uses of metals, semi-metals and non-metals

Metals

The uses to which we put metals depend on their properties.

Aluminium

Aluminium is used for pots and pans, window frames and ladders (Figure 3.1). In comparison with other metals, it has a low density so things made of aluminium are easy to lift and move about. Aluminium is soft enough to be easily moulded into shapes such as window frames, but strong enough to support the weight of a person on a ladder. Aluminium is a good conductor of heat so heat from a flame is quickly conducted to the food in an aluminium pan. Aluminium is not attacked by damp air so things made of aluminium will not corrode. This is because of the protective film of aluminium oxide which forms on the surface of the metal. Aluminium also has many industrial uses (Figure 3.2). What properties of aluminium make it suitable for building aircraft bodies?



Fig 3.1 Household objects made from aluminium.



Fig 3.2 Aircraft fuselages are made from aluminium.

Iron and steel

Iron and steel are used for construction work, car bodies, engines and tools. Steel is very strong. Things built with steel will keep their shape when subjected to a load. Car bodies do not distort when people get into the car. Steel is very hard so engines don't easily wear out. Steel tools do not bend easily when forces are applied to them but pure iron distorts easily (Figure 3.3).

A disadvantage of steel (and iron) is that it corrodes (rusts) in moist air (this section, Unit 3).

What properties of steel make it suitable for construction work?

Steel may also be seen in the form of 'galvanised steel' – steel which has been coated with the metal zinc. The zinc reduces corrosion (this section, Unit 3). Water storage tanks are often made of galvanised steel.

Gold

Gold is expensive, it is a precious metal. It is also called a *noble* metal, due to its unreactive nature towards most

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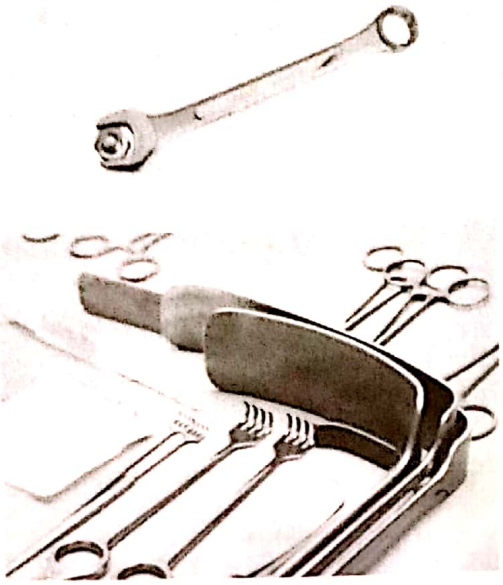


Fig 3.3 Some objects made from iron and steel.

chemicals – it does not corrode or tarnish easily in air. Added to this, its lustrous and attractive yellowish colour makes it a choice metal for ornaments and jewellery e.g. earrings, necklaces and bracelets. Gold is also one of the softest metals. It is the most malleable and ductile of all metals. It can therefore be beaten into the widest and thinnest sheet (0.000 013 cm) and be drawn to the longest distance (12 g to about 100 km). These properties combined with its high electrical conductivity means that it also finds uses in electrical and electronic equipment.

Gold reserves serve as an important reference in international banking and financial transactions between countries. In Ghana gold ornaments and the metal are an important part of a chief's regalia and wealth. This regalia are often displayed when a chief sits in state (Figure 3.4).

Other metals

- **Copper** is used to make electric wires and other parts of electrical fittings. It is also used to make pipes for transporting water and gas.
- **Chromium** has a high resistance to corrosion. It is used in the electroplating of mild steel and to make stainless steel.
- **Cobalt** is often used with iron to make powerful magnets. One of its isotopes, cobalt-60, is radioactive and the radiation from it is used in the treatment of cancers.

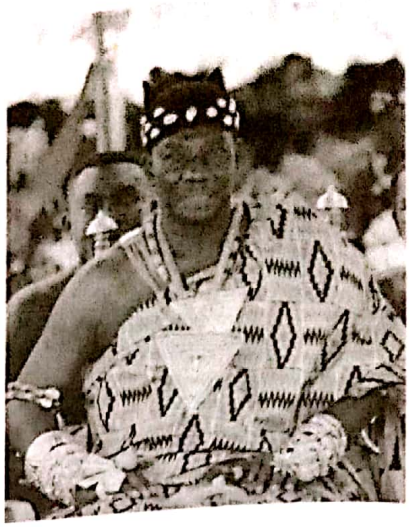


Fig 3.4 A chief's gold regalia.

- **Magnesium** is a reactive metal of low density. It is used for some of the low-density alloys, often with aluminium, which are used to make aircraft bodies.
- **Mercury** is the only metal which is a liquid at room temperatures. It is widely used as the liquid in thermometers.
- **Nickel** is a strong non-corroding metal. It is a constituent of some alloys such as stainless steel. It is used also as a catalyst in some industrial processes, such as making margarine from hydrogenated oils.
- **Platinum** is a rare, unreactive metal like gold and silver. It is often used for making items of jewellery. However, more important uses are in electrical contacts and electrodes and as a catalyst in some industrial processes. It is the best catalyst to use in the Haber process for the manufacture of ammonia but because it is so expensive, for reasons of economy, an iron catalyst is usually used.
- **Plutonium** is a radioactive metal. The isotope plutonium-239 is the fuel of a certain type of nuclear reactor called a fast-breeder reactor.
- **Silver** is a precious metal and is often used to make jewellery. It is an excellent electrical conductor and is also widely used in photographic emulsions.
- **Sodium** is a very reactive metal. Liquid sodium is used as the coolant in fast-breeder nuclear reactors.
- **Tin** is resistant to corrosion. It is used in the manufacture of 'tin' cans. These are not made of pure tin, but mild steel sheet coated with a thin layer of tin.
- **Titanium** is a strong, low density, non-corroding metal. It is used in the construction of aircraft bodies.

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- **Uranium** is a radioactive metal. One of its isotopes, uranium-235, is the fuel for many of the world's nuclear power stations.
- **Zinc** has good resistance to atmospheric corrosion and is used to protect steel (this section, Unit 3). It is also used in alloys (see below), and as an electrode in batteries and cells.

ACTIVITY 3 To list as many metals as you know and discuss their uses

1 On the left-hand side of your page, make a list of as many metals as you can. You should include the ones we discussed and any others you know.

2 Alongside the name of each metal, state some of the things it is used for.

3 Work *in groups* to choose some of the metals from your list. Discuss how the properties of each of these metals relate to its use. You may need to look up the properties of some metals elsewhere in this book or in other reference books.

Non-metals

- **Argon** is an inert gas used to provide an inert atmosphere for welding, in electric bulbs and fluorescent light tubes.
- **Carbon** exists in more than one physical form, the property known as **allotropy**. The allotrope graphite is used for electrodes, lubricants in machinery, pencil 'leads' and for controlling reactions in nuclear reactors. Diamonds are a gemstone used in jewellery. Because of its extremely hard nature it is used for cutting glass and ceramics. Charcoal is used as a fuel. As activated carbon it is used as an absorbent in purification processes.
- **Chlorine gas** is used to make disinfectants and bleaches, many organic solvents and plastic such as PVC.
- **Hydrogen** is used in the manufacture of ammonia and of hydrogenated fats e.g. margarine, in filling balloons and in welding. It is potentially of great use as a fuel because it is non-polluting.
- **Neon** is an inert gas. It is used in neon lights or signs and gas lasers.
- **Oxygen** is used in the manufacture of steel, in oxygen tents in hospitals, in oxy-ethyne (acetylene) and oxy-hydrogen welding and in rocket fuels.
- **Sulphur** is used mainly in the manufacture of tetraoxosulphate(VI) acid, H_2SO_4, in the manufacture of rubber, dyestuffs, and wood pulp for making paper. It is also used in making insecticides and fungicides since its products are toxic to smaller organisms.

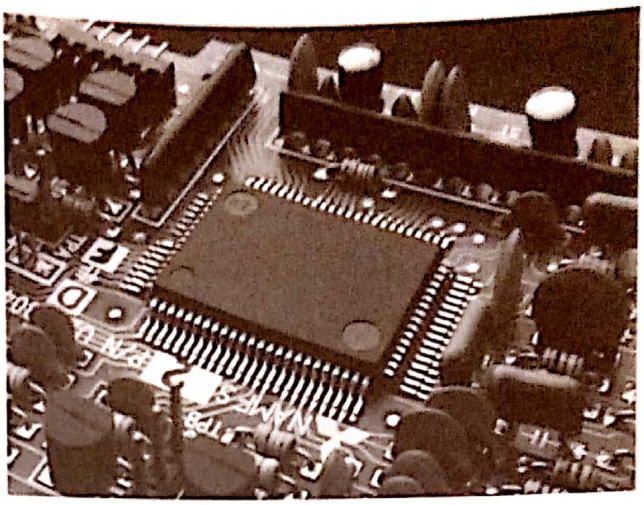


Fig 3.5 Transistors and microchips.

Semi-metals

Examples are silicon, gallium and germanium. One important use of semi-metals, silicon in particular, is in the production of semiconductors. Pure silicon is a poor conductor of electricity but when small amounts of other semi-metals such as boron or germanium are added as an impurity it becomes a good conductor or semiconductor chip or microchip. Microchips are tiny in size, compact in shape and of cheap cost. Silicon microchips and electrodes make the transistor component. When a tiny complex electronic circuit is etched or built on a chip it is called an **integrated circuit** (IC) (Figure 3.5). Modern electronic equipment contains thousands or millions of transistors often built in integrated circuits to carry out various operations. Microchips are used in almost every modern electrical device such as TVs, computers, calculators, water and electricity prepaid cards, vehicles, and mobile phones.

Alloys – their uses and advantages

An **alloy** is a uniform mixture of a metal and another metal or a non-metal. Alloys are often prepared by mixing their constituents in the molten state. An alloy is more useful for specific purposes than any single constituent. For example, steel is stronger and tougher than pure iron, which is soft and not strong enough to be used in the construction of bridges and parts of

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Table 3.4 Some common alloys

Alloy	Elements contained (approximate proportions)	Properties / advantages / uses
brass	copper 70%, zinc 30%	Yellow, lustrous / does not corrode easily / decorative containers, musical instruments
bronze	copper 85%, tin 15%	Yellow-brown / harder than copper and tin / statues, coins, medals, metal work, machine parts
duralumin	aluminium 96%, copper 4%, traces of manganese, magnesium and silicon	Light and strong / does not corrode / aeroplane body, railway coaches and ships, parts of prefabricated houses
nichrome	nickel 80%, chromium 20%, traces of manganese, silicon and carbon	Hard / can withstand high temperatures, good electrical resistor / heating elements in electric kettles and water heaters
solder	lead, tin in various proportions	Soft, low melting point / used for joining metals and electronic circuit parts
steel	iron 99% with less than 1% carbon by mass, traces of sulphur and phosphorus	Has high tensile strength / resists corrosion, can be tempered / construction of bridges, buildings, vehicle parts
stainless steel	iron 79%, chromium 18%, nickel 2%, traces of manganese, silicon and carbon	Decorative, stronger than iron / resists corrosion / cutlery, surgical instruments, decoration of automobiles, jet plane parts, food processing materials

machines. Stainless steel does not corrode but pure iron does. Duralumin has a greater tensile strength than aluminium or magnesium and is more suitable for building aeroplane bodies than aluminium. Table 3.4 contains information about some common alloys.

The composition of some alloys varies. For example, in solder, the proportions of lead and tin are varied in order to produce solders of differing melting points. Different types of steel contain differing amounts of carbon.

ACTIVITY 4 To find the composition of some alloys

1 Here is a list of alloys: aluminium bronze, cupro-nickel, German silver, Invar, pewter, phosphor bronze, Wood's metal, type metal, nichrome and dentist amalgam.

2 Find out (by asking people or looking up in reference books) what elements are mixed together to make these alloys.

3 Find out what these alloys and those listed in Table 3.4 are used for and give reasons for their use.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 Which of the following is a semi-metal?
- **A** potassium
- **B** chlorine
- **C** silicon
- **D** copper

2 Which of the following is a property of a typical non-metal?
- **A** good conductor of heat
- **B** low density
- **C** high melting point
- **D** good conductor of electricity

3 Brass is an alloy of
- **A** copper and tin
- **B** copper and zinc
- **C** lead and tin
- **D** nickel and chromium

4 Duralumin is an alloy used in the construction of aircraft because it
- **A** has a low melting point
- **B** is attractive in appearance
- **C** is very light and strong
- **D** is resistant to corrosion

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5 Tungsten metal, W, is used as a wire in incandescent electric bulbs and vehicle engine spark plugs because it:

I has a high lustre
II is ductile
III has a very high melting point
IV has semi-metal properties

A I and II
B II and III
C III and IV
D IV and I

6 Draw a sketch of the periodic table and show the positions of metals, non-metals and semi-metals in it.

7 Make a list of some of the properties of typical metals and state how they are different from the properties of typical non-metals.

8 List three different uses of:

a) copper
b) iron/steel
c) aluminium.

9 a) What is an alloy?
b) State what elements are present in the following alloys and give one use of each alloy: bronze, nichrome, duralumin.

10 a) State the alloy used in building the structure of an aeroplane.
b) Explain why the alloy is preferred to any of its two components used alone.

11 Fill in the blank spaces in the table below on metals non-metals, semi-metals and plastic.

Element	Classification as a metal, semi-metal or non-metal	Use
a) Iron		
b) Argon		
c) Silicon		
d) Graphite		
e) Uranium		
f) Germanium		
g) Sulphur		

12 a) (i) State one typical property of a metal.
(ii) Explain briefly how the property stated in (a) (i) is applied in a given use.
(iii) Write one chemical equation to show one chemical property of any given metal.
b) Electrical power can be carried from one point to another using cables or wires insulated on poles.
(i) Explain the use of a suitable metallic that can be used to make the cables.
(ii) Explain **one** advantage and **one** disadvantage that a wooden pole may have over the metallic alloy pole.

13 a) Explain briefly why:
(i) Steel instead of iron is used in making car bodies
(ii) Aluminium frying pans are fabricated with a wooden handle
(iii) Electronic equipment may contain gold parts
(iv) Lead pipes are no more used in transporting water.
b) Copper has higher electric conductivity than aluminium, but aluminium cables are better suited for long distance electric power transportation.

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2 Extraction of metals

Learning objectives

After studying this unit, you should be able to:

describe the chemical extraction of aluminium and gold from their ores.

Background information

Aluminium, gold and iron are well known and used elements and metals. Aluminium is the most abundant element in the earth, gold the most treasured and iron the most widely used. Aluminium and iron exist naturally combined as compounds in their ores, whilst gold occurs naturally as the pure or native metal in its ore. As metals in their ores, they are virtually useless. The pure metals have to be extracted from their ores to make them useful to serve humans. The extraction process is chemical in nature – the ores are purified and made to go through chemical reactions to obtain the pure metal.

Extraction and purification of aluminium

Ore deposits

In Ghana large deposits of **bauxite**, the main ore of aluminium, are located in the Nyinahin and Kibi areas in the Eastern region. The deposit in Nyinahin is being mined and exported. Guinea, Sierra Leone, Jamaica, Australia and Indonesia are also exporters of bauxite.

Production of alumina

Bauxite contains the hydrated oxide of aluminium with the formula $Al_2O_3.nH_2O$ (n = 1, 2, 3) and also sand (silica, SiO_2) and iron(II) oxide (haematite) impurities. These impurities are removed before the aluminium metal is extracted. This is done by dissolving (digestion or leaching) the crushed, dried ore in hot concentrated sodium hydroxide, NaOH. Aluminium oxide and silica, being amphoteric, react with sodium hydroxide to form soluble aqueous solutions of the complex salt, $NaAl(OH)_4(aq)$ and Na_2SiO_3 respectively. Iron(II) oxide is basic and will not react or dissolve in the sodium hydroxide. Its solid is filtered off. The reaction equations are:

$$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow \underset{\text{sodium tetrahydroxoaluminate(III)}}{2NaAl(OH)_4(aq)}$$

$$SiO_2(s) + 2NaOH(aq) \rightarrow N_2O(l) + \underset{\text{sodium trioxosilicate(IV)}}{Na_2SiO_3(aq)}$$

The solution of sodium tetrahydroxoaluminate(III) and sodium trioxosilicate(IV) is then seeded with crystals of pure aluminium hydroxide, $Al(OH)_3$, to precipitate solid aluminium hydroxide. The solid is washed, filtered and then roasted (strong heating) to 1270 K in kilns. The hydroxide loses water to give pure aluminium oxide (alumina). The equation is:

$$2Al(OH)_3(s) \xrightarrow{\text{roast}} Al_2O_3(s) + 3H_2O(g)$$

Aluminium cannot be extracted from alumina by heating with carbon because aluminium is too reactive. It is obtained by electrolysis, by passing an electric current through a melt containing alumina using graphite electrodes. This is called the Hall process. The apparatus used is called a Hall cell (Figure 3.6).

Electrolysis of alumina

The alumina is dissolved in molten cryolite, Na_3AlF_6. This mixture melts at a much lower temperature than pure alumina, so the cost of heating the cell is less.

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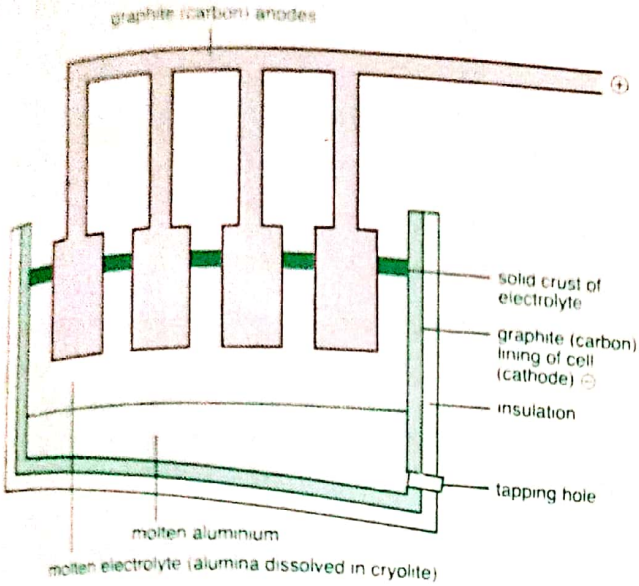


Fig 3.6 The extraction of aluminium from alumina in a Hall cell.

During electrolysis, aluminium oxide is decomposed into aluminium and oxygen. Aluminium ions are attracted to the negative electrode (cathode) where they gain electrons to become aluminium atoms. The molten aluminium sinks to the bottom of the cell from where it is run off. The equation is:

$Al^{3+} + 3e^- \rightarrow Al(s)$

aluminium ion → aluminium atom

Oxide ions are attracted to the positive electrode (anode) where they lose electrons to become oxygen molecules. The equation is:

$2O^{2-} - 4e^- \rightarrow O_2(g)$

oxide ions → oxygen molecule

The Hall cell operates at a temperature of 900°C. At this temperature, oxygen reacts with the carbon anode to form carbon dioxide. The result is the anode is continually eaten away by the oxygen produced and it has to be frequently replaced. Figure 3.7 illustrates the entire process.

ACTIVITY 1 Study visit to an aluminium extraction plant, Volta Aluminium Company (VALCO), Tema

1 Your teacher will arrange for the visit and announce the date.

2 **a)** Study the flow chart in Figure 3.7.
b) Write short notes or equations at each stage where chemical changes take place.

3 **a)** Read through the text in this book on the extraction of aluminium and other texts related to it.
b) Each student should write out at least two questions to be asked when the class gets to the extraction plant.

4 The teacher should have a short meeting with the class to prepare for the visit.

5 After the visit, students should *work in groups* of five. Each group should present a report of about 500 words to discuss in class. The best report adjudged by students should be published in the school magazine or elsewhere, under an attractive title.

Note: Schools which cannot make such a visit, should, if possible, show a video on aluminium production.

Effects on the environment

In Ghana, the aluminium plant at Tema is a source of air pollution by poisonous fluoride gases. Fluorides are also known to destroy some types of vegetation. Mining operations can disfigure the landscape with pits and heaps of unwanted materials.

- **Deposit of fluorides on nearby plant/vegetable foliage** – effect is poisonous to animal and human consumption and the foliage itself.
- **Slag formation** – unwanted by-product e.g. red mud [$Fe(OH)_2$ and $Fe(OH)_3$], from the filtration stage,

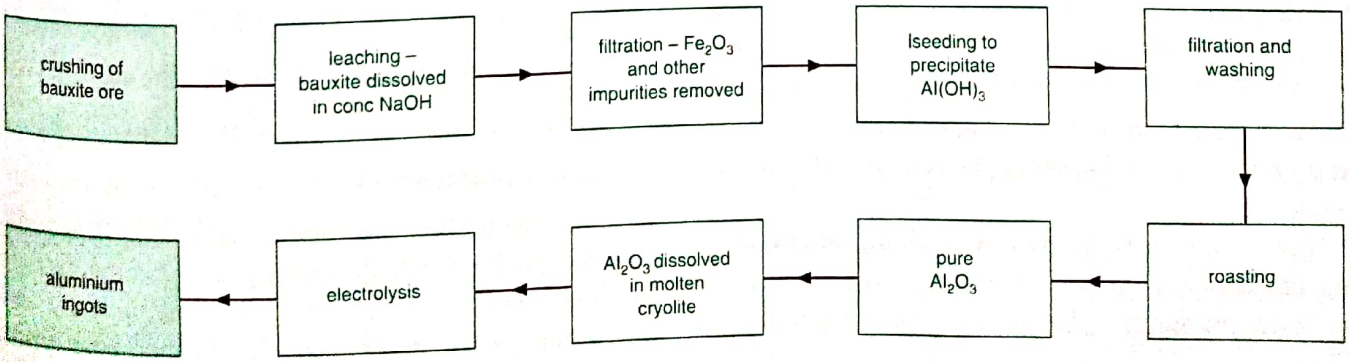


Fig 3.7 Flow diagram for the extraction of aluminium.

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highly alkaline, occupies space in the landscape and destroys natural vegetation.

- **Emission of CO, CO_2 and SO_2 from the cell** – pollutant by-products: CO and CO_2 is formed by combination of carbon electrode material and oxygen and SO_2 from the combination of sulphur impurities in electrode and oxygen at the anode.
- **Carbon particles dust** – pollutant from the fabrication of the carbon electrode.

Extraction and purification of gold

Ore deposits

The former name of Ghana was the Gold Coast. The name comes from the wide occurrence and trade in the precious metal in Ghana even before the arrival of Europeans to its shores. The two main mining towns in Ghana are Obuasi and Tarkwa in the Ashanti and Western regions respectively.

Gold has been the first or second leading export of Ghana for a long time. It competes with cocoa as the leading export commodity. Gold has therefore provided an important support for the Ghanaian economy in earning valuable foreign exchange to provide social services such as education and health. Other countries which have large and economic ore deposits in Africa are South Africa, Zimbabwe, Tanzania and Guinea. Other countries with large gold deposits outside Africa are Australia and Canada.

Gold is unreactive and therefore does not occur chemically combined in its ore as in the case of aluminium. Gold occurs as the uncombined or native metal trapped in the structure of other metal ores such as haematite, Fe_2O_3, iron pyrites, FeS_2, and iron arsenopyrites FeAsS. These are described as **gold-bearing ores**. The method of treatment to obtain pure gold depends on the type of ore. There are two main types – the high-grade oxide ore dug mainly from the surface and the sulphide ore dug from both the surface and underground. The ore types may differ from mine to mine.

The main process used in extracting gold at Obuasi is summarised as follows. The chemical process is the same or similar in other gold mines in and outside Ghana.

Extraction processes

Crushing and milling

The ore is crushed and milled into a fine powder. Water is added to form a watery mixture of insoluble ore particles called slurry.

Leaching, adsorption and desorption

For an oxide ore, the slurry is dissolved in a solution of sodium cyanide and oxygen gas bubbled into it to form a soluble gold cyanide complex ion, $[Au(CN)_2]^-$ with the IUPAC name, dicyanoaurate(1) ion, aurum being the Latin name of gold. This process is known as leaching. It means adding a suitable solution to a mixture to dissolve a desired substance followed by separation of the insoluble substances. The equation is:

$$\underset{\text{gold}}{4Au(s)} + \underset{\text{sodium cyanide}}{8NaCN(aq)} + \underset{\text{oxygen}}{O_2(g)} + \underset{\text{water}}{2H_2O(l)} \rightarrow \underset{\text{sodium dicyanoaurate(1)}}{4NaAu(CN)_2(aq)} + \underset{\text{sodium hydroxide}}{4NaOH(aq)}$$

The gold complex ion is then adsorbed on the surface of carbon. Adsorption means strong attachment or adhesion to the carbon. The carbon is obtained from charring coconut shells at very high temperatures. The adsorbed gold complex ion is then separated from the coconut carbon in the process called desorption. This involves washing the adsorbed gold complex from the surface using sodium cyanide solution ready for electrolysis. The process of adsorption and desorption increases the concentration of the gold complex.

Electrolysis

The gold complex is electrolysed at this stage in the process called electrowinning – recovering the metal from the ore complex using electricity. Gold is deposited at the steel cathode. The equation is:

$$[Au(CN)_2]^- + e^- \rightarrow Au(s) + 2CN^-(aq)$$

Oxygen gas is produced at the anode. The equation is:

$$2H_2O(l) - 4e^- \rightarrow O_2(g) + 4H^+(aq)$$

Calcining and smelting

The gold on the steel cathode is calcined. Calcination is the process by which the crude gold is heated strongly without melting in order to drive out moisture and burn out volatile impurities. The calcined gold finally goes through smelting in which the gold is heated with

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Fig 3.8 Smelting stage of gold production.

a mixture of chemicals called a flux. The mixture is heated to melt the gold into a yellow liquid and finally into gold bars (ingots) called gold bullion.

Sulphide ore processing

The presence of sulphide compounds like FeS and FeAsS in ores make it impossible for the sodium cyanide solution to dissolve the native gold. To get around this problem, additional steps are taken to concentrate the gold cyanide solution.

Gravitation separation

The gold slurry obtained after milling is passed over specially arranged tables where it is shaken to separate the heavier gold particles. The native gold particles are then sent for calcining and smelting.

Flotation

The remaining slurry from the gravitation separation is mixed with selected chemicals. The chemicals create air bubbles which make the sulphide ore float to the surface of the liquid as a froth. The froth is then skimmed off for roasting.

Roasting

The pyrites and arsenopyrites ores are roasted at high temperatures to oxidise the sulphur and arsenic elements out of the ores to remove them. The main product is iron(III) oxide. The simplified equations are:

$$4FeS_2(s) + 11O_2(g) \rightarrow 2Fe_2O_3(s) + 8SO_2(g)$$

$$FeAsS(s) \rightarrow FeS(s) + As(g)$$

$$4FeS(s) + 7O_2(g) \rightarrow 2Fe_2O_3(s) + 4SO_2(g)$$

Roasting produces a spongy iron(III) oxide, Fe_2O_3, ore with the native gold metal still trapped in it. The spongy oxide is suitable for leaching. Note that the by-products of this process, sulphur oxides and gaseous arsenic metal, which is finally oxidised to As_2O_3, are toxic.

Cyanidation (leaching)

The roasted ore is dissolved in sodium cyanide solution (cyanidation) and oxygen gas is bubbled through it to form the soluble gold cyanide complex. The insoluble impurities are filtered off. The solution is ready for precipitation.

Precipitation

Zinc metal is added to the soluble gold complex solution to precipitate the gold metal.

$$2NaAu(CN)_2(aq) + Zn(s) \rightarrow 2Au(s) + Na_2Zn(CN)_4(aq)$$

The crude gold is sent for calcining and smelting as described earlier.

Bio-oxidation

In another method used for sulphide ores, the steps are similar up to the floatation stage. However, roasting is not carried out to oxidise the remaining sulphur and arsenic components. A new technology using useful microbes is applied. The microbes oxidise the pyrites and arsenopyrites into soluble products that can easily react with sodium cyanide. Bio-oxidation is followed by leaching, adsorption, desorption, electrowinning, calcining and smelting to obtain bullion gold.

The methods are outlined in the flow diagram in Figure 3.9. It is important to note that at any stage in all the methods, the wastes from the ore (tailings) produced are put into a tailings dam to be passed through a second series of treatments (recycle), to extract any gold that remains.

Galamsey

Galamsey is the local name given to the work of extraction by small scale miners of gold and diamonds in Ghana. The main steps used in their operations to obtain gold are as follows.

1 The gold-bearing ore (or tailings from a treatment plant) is washed with water in a pan to remove lighter impurities.
2 The mixture in the pan is poured over a heavy cloth on an inclined table. The cloth is strong enough to allow the water to pass and hold the heavier gold-

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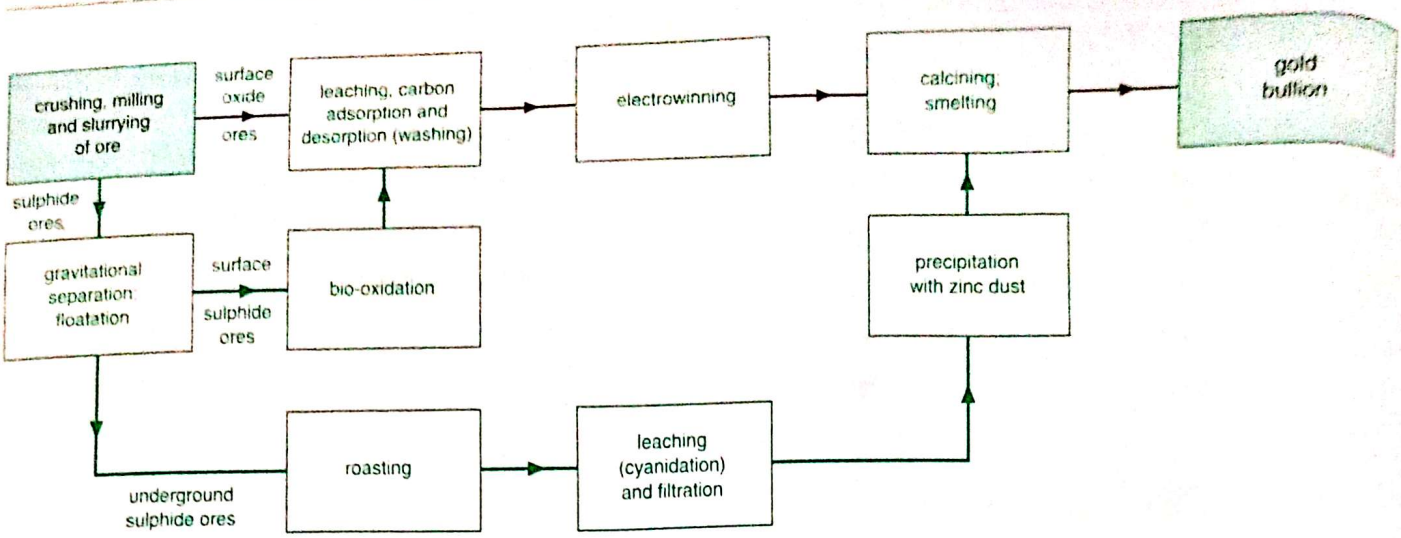


Fig 3.9 Flow diagram for the extraction of gold.

bearing ore. The ore is washed repeatedly to obtain a small concentrate of the gold-bearing ore.

3 The concentrate on the cloth is then washed into a pan with water and decanted.

4 The concentrate is rubbed well with mercury to form a uniform mixture (**amalgam**). The remaining impurities do not dissolve.

5 The gold amalgam is put into a clean white piece of cloth and squeezed tightly. The crude gold forced out is a grey white colour due to mercury impurity.

6 The crude gold is washed again with water in a container. The heavier mercury falls to the bottom and the gold remains on top. The crude gold is carefully collected, ready to be sold.

The crude gold produced by any of the methods is not pure gold. It is exported outside Ghana to be finally purified by refining.

Effects on the environment

Roasting of arsenide and sulphide ores pollutes the atmosphere with gaseous arsenic and sulphur oxides. The use of mercury to concentrate gold, results in the contamination of drainage water by mercury. The land is disfigured by mining operations and polluted by dumping of solid wastes. Galamsey operations, e.g. the recovery of alluvial gold, create damage to the soil, vegetation and water bodies.

Other effects on the environment are:

- **Destruction of the ecosystem** – resulting in the natural habitat of organisms being destroyed
- **Land degradation** – so much so that it cannot support the growth of crops and vegetation
- **Dust pollution of the air** – with dust from excavation and milling
- **Pollution of water bodies by cyanide leakage** – water bodies are poisoned leading to death of aquatic life and poisoning of domestic water sources; cyanides act by blocking the ability of human cells to use oxygen adequately
- **Noise pollution** – due to machinery and it can affect eardrums of mammals
- **Production of SO_2 and As_2O_3 gas from roasting of sulphide ores** – the gases are poisonous and cause acid rain that can destroy vegetation, top-soil, some organisms and other physical structures; corrode statues. As_2O_3 is toxic to humans.
- **Mercury poisoning** – mercury vapour from Galamsey operators is a potential source of poisoning.

ACTIVITY 2 How to minimise environmental damage caused by aluminium and gold extraction processes

In this unit we touched on the economic benefits to Ghana of gold and aluminium production and also on the negative effects to the environment – pollution of land, air and water sources from physical extraction of the ores and the chemical processes involved in purification.

1 *Work in groups* to discuss the possible long-term consequences of this environmental damage and how it could be prevented, minimised, or put right. Each group should consider one particular aspect, e.g. damage to land from mining wastes, air pollution by emitted gases, etc. Consider the costs of your solutions in relation to the economic benefits of extraction.

2 Put together a short presentation to explain your ideas to the class.

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Social and economic impact of aluminium and gold production on an economy

Investment in the industry creates jobs and may promote general physical development of infrastructure in the area.

Tax earnings, royalty receipts and foreign exchange returns from companies support the general economy to grow. However, inequitable use of earnings and physical degradation of the environment has a potential of causing social and armed tension and conflicts, e.g. in the case of gold and petroleum production in Ghana and Nigeria respectively.

The negative impacts above can be minimised or totally removed mainly through:

- strict enforcement of mining laws and enactment of new laws on pollution
- reforestation of degraded forests and vegetation
- increase in royalties and its equitable distribution to affected communities
- use of modern equipment to reduce the pollutant emissions to acceptable levels
- control and education of Galamsey operators on the toxic effects of use of mercury
- watering of dusty operation areas to minimise dust formation.

Self check

For questions 1 to 6, choose the letter that refers to the correct option.

1 Which of the following metals is obtained from its ore by electrolysis?
- A aluminium
- B gold
- C copper
- D iron

2 Bauxite, the ore of aluminium, is
- A aluminium oxide
- B aluminium sulphate
- C aluminium chloride
- D sodium aluminium fluoride

3 Which of the following is a stage in the extraction of gold from its ore?
- A filtration of iron (II) oxide impurity from the ore
- B leaching with sodium hydroxide, NaOH solution
- C roasting of the purified ore of the metal
- D electrolysis of the cyanide solution of the ore

4 Possible sources of pollution in the extraction of gold is
- I The production of acidic gas such as sulphur (iv) oxide from the roasting of the ore containing compounds of sulphur
- II Production of plastic and food leftovers from the workers
- III Uncontrolled/accidental spillage of sodium cyanide mixtures into water sources
- IV Bacterial oxidation

- A I only
- B IV only
- C I, II, III and IV
- D I, II and III

5 The following are protective measures or benefits to a community near aluminium and gold extraction industries:
- I Increase in employment opportunities
- II Increase in demand and supply of skilled labour
- III Regular monitoring by an Environmental Protection body, Legislation and its enforcement to re-vegetate the ecosystem
- IV Production of toxic gas such as CO and SO_2

- A I, II, III and IV
- B I, II, IV
- C I and III
- D III and IV

6 The following are disadvantages or pollution effects on a community near a gold or aluminium extraction industry:
- I Likely poisoning of water sources by cyanide leakage
- II Deposition of waste slag
- III Earning of foreign exchange
- IV Deposition of fluoride and dust particles on vegetation

- A I, II, III and IV
- B I, II, IV
- C I and III
- D III and IV

7 Describe briefly the extraction of aluminium from its main ore.

8 a) Draw a labelled diagram to show the structure of a Hall cell.
b) Write chemical equations for the reactions which occur at each of the electrodes in a Hall cell.

9 Write balanced equations to represent the following:
a) Oxidation reaction of leaching of gold metal, Au in the ore with aqueous sodium cyanide, NaCN in the presence of oxygen, O_2 and water H_2O to produce soluble complex sodium dicyanoaurate (i), $Na[Au(CN)_2]$ and NaOH.
b) Precipitation of gold metal by zinc solid dust reacting with $Na[Au(CN)_2](aq)$ to produce $Na_2Zn(CN)_4(aq)$.
c) Strong heating or roasting of wet $Al(OH)_3$ slurry to give dry powder of alumina.

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3 Rusting

Learning objectives

After studying this unit, you should be able to:

explain the process of rusting.

Background information

Air is reactive towards many materials left in it. Many metals corrode or tarnish in air. Oxygen and water vapour are the most reactive components of air. Together or separately, they react with reactive metals to form their oxides in a process called oxidation. For some of the metals this reaction continues without stopping, wearing off the metal and gradually leading to their destruction. Iron is the most widely used metal and therefore its corrosion is also widespread. Air and water vapour attack it and this oxidation reaction is referred to as rusting. Rusting is destructive and costly and should be prevented or minimised as much as possible.

Chemical reactions of aluminium and iron in air

A common feature of these metals is that they readily react with oxygen in the atmosphere to form oxides (see Table 3.3 on page 338).

The surface of freshly cut aluminium is attacked rapidly by oxygen from the air. The surface becomes coated with a thin layer of aluminium oxide. This oxide layer is very tough and prevents further contact and reaction between aluminium and oxygen or air. Thus the thin oxide layer protects it from further corrosion. Therefore aluminium metal develops a protective coating and does not corrode even though the fresh metal is very reactive (Figure 3.10). In a similar way zinc and lead metals also forms a protective oxide coating and do not corrode. Copper corrodes, first forming a black coating of the oxide and then a green coating called patina or verdigris.

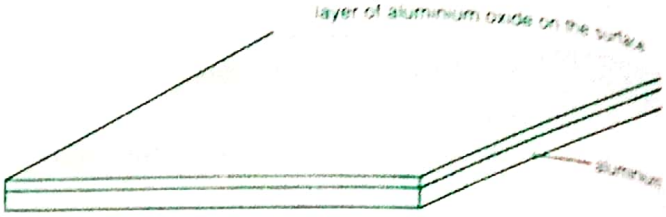


Fig 3.10 The protective oxide layer on a piece of aluminium (enlarged).

Iron reacts with oxygen in the air, providing there is moisture present. The result is what we commonly call **rust**.

ACTIVITY 1 To study the effects of air on pieces of polished iron and aluminium metal

1 Collect the following from your teacher: a piece of aluminium, a piece of iron, some fine abrasive paper (sandpaper).
2 Rub the surface of the piece of iron with the abrasive paper to remove any dirt, rust and marks.
3 Repeat step 2 with the piece of aluminium.
4 Make a note of the appearance of both pieces of metal.
5 Leave both pieces of metal exposed to the air outside for one week.
6 Carefully examine the pieces of metal and write down any changes you see. Compare the amount of corrosion on each piece of metal. Explain your observations.

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Process of rusting of iron – corrosion, oxidation and reduction

Corrosion is the general term used for the chemical reaction of metals with air and water vapour. In the process, the metal wears off gradually or forms a surface layer of its oxide and other compounds. Corrosion of iron is called rusting. **Rusting** is the reaction of iron with oxygen and water vapour in the air to form a brown-red solid of hydrated iron (III) oxide, $Fe_2O_3.xH_2O$. In the process the iron metal tarnishes and wears off. Both oxygen and water are necessary for iron to rust. Without one of these conditions rusting cannot take place. Regardless of the air temperature, rusting will take place when the two are present. Air contains oxygen gas and water (vapour) or moisture, therefore, iron rusts in it.

When iron rusts, oxygen and water combine with the iron to form rust, hydrated iron (III) oxide, $Fe_2O_3.H_2O$. Rusting of iron can be represented by the equation:

$$2Fe(s) + \tfrac{3}{2}O_2(g) + H_2O \rightarrow Fe_2O_3.H_2O$$
(porous brown solid – rust)

or

$$4Fe(s) + 3O_2 + 2H_2O \rightarrow 2Fe_2O_3.H_2O(s)$$
(porous brown solid – rust)

More water vapour can be absorbed to form $Fe_2O_3.xH_2O$, where x can be one, two or three. Rust is a red-brown solid that is attached to the surface of the iron. It makes the iron metal tend to expand compared to the original metal. When the amount increases, it flakes off the body of the metal if the metal body is free in the air. If the original metal body is not free it tends to expand exerting pressure on the adjoining materials and finally flaking off.



Fig 3.11 Rusting happens when iron comes into contact with oxygen and water.

Iron undergoes oxidation and oxygen is reduced in the rusting process. This can be explained by looking closely at the equation for rusting. The oxidation state of iron, Fe has increased from 0 to 3+ (Fe (III) or Fe^{3+}). On the other hand, the oxidation state of oxygen, O has decreased from 0 to 2– (O^{2-}). This means iron has lost electrons when it is oxidised and oxygen has gained electrons when it is reduced. This can be represented as iron losing electrons to be gained by oxygen:

$$Fe - 3e^- \rightarrow Fe^{3+}$$ (Oxidation: loss of electrons by iron)

$$O_2 + 4e^- \rightarrow 2O^{2-}$$ (Reduction: gain of electrons by oxygen)

Rusting is an electron transfer process or an electrochemical reaction. The presence of ions helps the flow of electrons and increases the rate of rusting or corrosion. This is why the presence of aqueous solutions of acids, alkalis and salts makes corrosion more extensive or faster.

Iron and steel have a high tensile strength and are comparatively cheaper than other metals and their alloys. They are widely used in construction of buildings and vehicle bodies, railway lines, household items and many other objects. Yet when exposed to moist air, they rust. The rusting process may take a long time to completely damage and destroy the iron structure. The damage and inconvenience caused by rusting, the hazards and accidents it may create and cause when rusted parts of structures and machinery give way are enormous. The cost of replacement of rusted items, and to prevent rust, is expensive all over the world.

In order to understand the basic type of chemical changes taking place during rusting we need to investigate the factors involved.

ACTIVITY 2 To investigate what conditions cause rusting

Part A

1 Collect the following from your teacher: test tubes with stoppers, iron nails which have been cleaned to remove any grease or oil, water which has been freshly boiled

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to remove all of the air dissolved in it, silica gel, liquid paraffin and labels.

2 Label three test tubes A, B and C. Place a nail into each test tube and treat them as follows.

Tube A – fill the test tube with ordinary tap water and seal it with a stopper.

Tube B – fill the test tube with water which has been boiled to remove all dissolved air, cover the water with a layer of liquid paraffin and seal it with a stopper.

Tube C – place a small amount of silica gel in the test tube and seal it with a stopper (silica gel absorbs water and keeps the atmosphere dry).

3 Leave the test tubes together in the laboratory for one week.

4 After one week, observe the appearance of the nails.

5 From your observations, state what conditions are necessary for rusting to take place.

Part B

6 Label three more test tubes D, E and F and treat them as follows.

Tube D – fill with dilute hydrochloric acid, put a clean piece of nail in it and leave it open or sealed.

Tube E – fill with salt solution, put a clean piece of nail in it and leave it open or sealed.

Tube F – fill with tap water as with tube A but keep it in a warmer place outside the laboratory or heat the test tube every day.

7 Leave the test tubes together for one week.

8 After one week, observe the appearance of the nails.

9 From your observation in Parts A and B:
(i) state whether iron rusts faster in acid
(ii) state whether iron rusts faster in salt solution
(iii) state whether iron rusts faster at higher temperatures.

Since rusting is an electrochemical reaction, the presence of ions helps the flow of electrons and increases the rate of corrosion. This is why the presence of aqueous solutions of acids, alkalis and metal salts makes corrosion take place faster.

At a beach or along the coast, salt solution (NaCl) is carried in the air. This increases rusting of iron and steel structures, both in the open and indoors, compared with similar iron structures farther away from the sea. For example an iron nail will rust more rapidly in Accra, Tema or Cape Coast than will one in Kumasi or Sunyani.

Rusting also proceeds faster at higher temperatures. For this reason rusting would be expected to be faster in the northern part of Ghana provided there is sufficient moisture in the air.

ACTIVITY 3 To identify iron and steel structures which are rusted in the local area

1 Inspect iron and steel structures around your home and around your school for the presence of rust.

2 Is there any connection between the amount of rust and the place where the structure is or the job that it does?

3 Explain why rusting and its prevention costs the country a large amount of money each year.

Preventing rusting

By coating

Most methods of rust prevention involve placing a protective layer over the iron or steel to prevent any contact with air and moisture. The coating may be:

- grease or oil, e.g. engine parts (Figure 3.12)
- paint e.g. car bodies (Figure 3.13)
- a thin layer of non-rusting metal coated onto the iron and steel by **electroplating**, using an electric current e.g. chromium is electroplated onto the mild steel of car bumpers (Figure 3.13)
- plastic e.g. steel wire mesh fencing
- a thin layer of zinc, applied by dipping the item into a bath of molten zinc in a process called galvanising

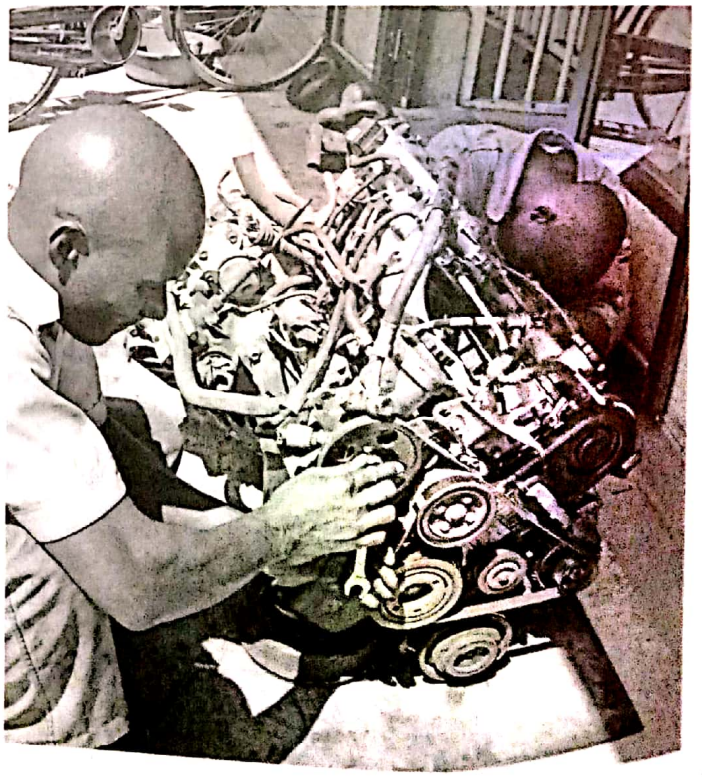


Fig 3.12

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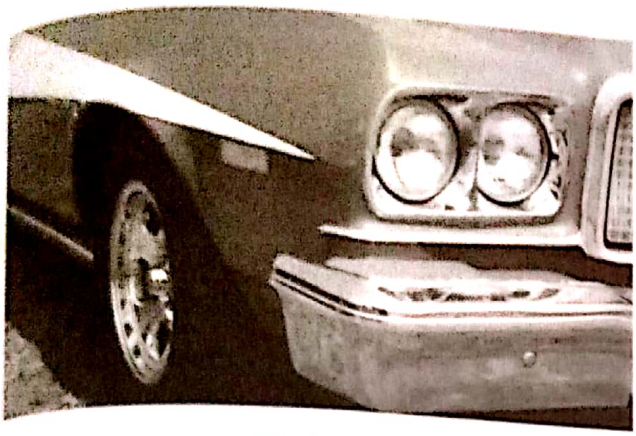


Fig 3.13



Fig 3.14

– galvanised iron is used to make buckets and corrugated sheets for roofing (Figure 3.14).

These methods of prevention of corrosion based on preventing contact with air and moisture become ineffective when the coating is damaged exposing the surfaces to air. Any small opening to air initiates rapid corrosion. For example, a painted metal railing will corrode rapidly immediately a crack develops exposing the metal to moist air. Food cans are made from steel plated with tin which is quite unreactive towards fruits and other acidic food. However, if the inner tin coating is punctured, the steel reacts rapidly with the acidic food contents, spoiling the food.

By alloying

Certain alloys of iron do not rust e.g. stainless steel which is used for surgical instruments and sometimes used to make tools and eating utensils.

Reactivity of metals, corrosion and sacrificial protection

Another method of preventing rusting involves connecting iron to a more reactive metal. As we saw in Table 3.3, metals react at different rates e.g. with water or acids. Calcium reacts with water rapidly, but iron reacts only with steam. Iron reacts with hydrochloric acid, but copper does not. In this, and many other ways, a rank order of activity of metals called a **reactivity series** can be drawn up (Table 3.5).

Table 3.5 A reactivity series for metals

Reactivity	Metal	Reaction with moist air
most reactive ↑	potassium	stored under oil as reacts vigorously with moist air
	sodium	as above
	calcium	oxide coating readily forms giving protection from further corrosion
	magnesium	as above
	aluminium	as above
	zinc	as above
	iron	rusts
	tin	
	lead	
	hydrogen	
	copper	a green coating (verdigris) forms
↓	silver	corrodes (tarnishes) when exposed over a period of time
least reactive	gold	does not corrode

A more reactive metal will displace a less reactive metal from a solution of its salt. For example, iron displaces copper ions from copper sulphate solution. We do not think of hydrogen as a metal but its reactivity is between lead and copper.

If iron is connected to a more reactive metal, such as zinc, the result is that the zinc corrodes not the iron. This is sometimes called **sacrificial protection**. Zinc is called a sacrificial metal because it reacts and sacrifices itself.

This has many applications. For example underground steel pipelines have blocks of zinc connected to them at intervals (Figure 3.15). The blocks are examined regularly and replaced as necessary. This is far more convenient and cheaper than having to renew lengths of pipeline.

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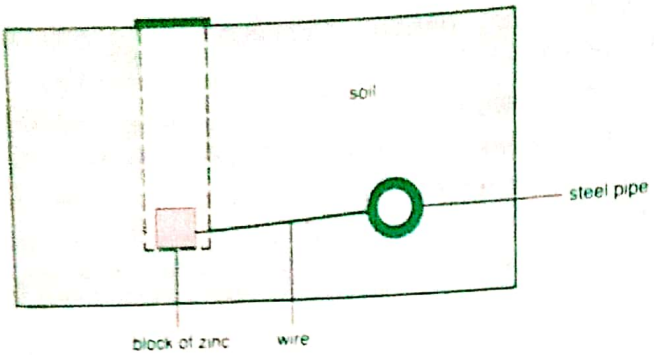


Fig 3.15 Protection of steel pipes by connection to zinc blocks.

The higher a metal is in the reactivity series, the more rapidly it corrodes (Table 3.5). The metals at the bottom of the reactivity series are much less susceptible to corrosion.

Gold, silver, and sometimes copper are all found as native metals in the ground. This is an indication of their low chemical reactivity. Metals higher up the series are far too reactive to remain as metals in the ground.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 Iron corrodes when it is in contact with
- **A** just air
- **B** just moisture
- **C** air and moisture
- **D** oil

2 Galvanising iron involves covering it with a thin layer of
- **A** plastic
- **B** grease
- **C** tin
- **D** zinc

3 Which of the following metals is at the bottom of the reactivity series?
- **A** potassium
- **B** copper
- **C** gold
- **D** aluminium

4 In building construction, many parts are reinforced with iron metal rods. It is advisable to wash sea-sand well with clean water before it is used in the construction process for the following reason:
- **A** Washing with clean water removes organic materials from the sea sand.
- **B** The temperature in the sand is reduced to slow down corrosion in the structure.
- **C** The washing dissolves and removes salt or any electrolyte which may aid corrosion of iron in building structures.
- **D** The resultant wet sand produces the strongest concrete in the building structure.

5 Rusting is often referred to as an oxidation or an electrochemical reaction because
- **I** electrons are gained and lost in the process
- **II** iron combines with oxygen in the air
- **III** the process can cause accidents

- **A** I, II and III
- **B** I and II only
- **C** II only
- **D** II and III only

6 **a)** Explain briefly the process of rusting and the conditions under which it occurs.
b) Briefly outline the different ways of protecting iron and steel from corrosion.

7 An electrical circuit is made up of insulated copper wires, a steel crocodile clip conductor and iron screw joints which can be connected to an electric power source. When the circuit is connected to a conductor, a small lamp in the circuit lights up. After many years the crocodile clip conductor and the iron screw joints developed brown surfaces. When the circuit was connected to a power source, with firm joints, the light did not come on.

Answer the following questions on the electrical circuit described.

a) Why was the copper wires insulated?
b) What is the name and formula of the brown solid that developed on the surface of the steel crocodile clip and connection joints.
c) Explain briefly what is preventing the lamp from lighting.
d) Describe briefly what remedial measure would you take to make the circuit conduct for the light to come on.

8 **a)** Provided other factors which cause corrosion are the same, would you expect rusting to occur faster or slower near or farther away from the sea? Explain briefly.
b) State two items that can rust at each of the following places
(i) home
(ii) outside the home.
c) Describe briefly how you would minimise or stop the corrosion process on one article in the
(i) home
(ii) outside the home.

9 **a)** State the two things necessary for iron to rust.
b) (i) What is the colour of the material produced when iron rusts?
(ii) What is the chemical formula of rust?
(iii) Write a balanced equation to represent the process of rusting of iron.
c) Explain briefly why rusting takes place at a slower rate in an air-conditioned room than in a normal air ventilated room.

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10 Explain the following observations or things which take place or exist around us.

a) a bronze statue will develop a light green surface coating

b) a piece of lustrous shining nail turns brown after a few days

c) exposed parts of a metal grid in a refrigerator corrodes despite the very low temperature in it

d) a steel bridge which is not maintained regularly may collapse one day

e) a plastic laminated wire mesh lasts longer than a bare steel one

f) blocks of zinc metal are attached to the steel body of a ships

g) a garden tool is often smeared with paraffin jelly

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1 Life cycle of pests and parasites

Learning objectives

After studying this unit, you should be able to:

1 identify some common pests and parasites of farm animals, humans and plants
2 explain the term life cycle and its relevance in the life of some plants and animals.

Background information

Humans, livestock and plants are all plagued by both pests and parasites. Pests cause direct physical damage to crops and livestock through their eating habits. They also indirectly cause diseases to them. This is because some pests transmit diseases by carrying the pathogens from sick persons or animals to healthy ones. Such pests are called **vectors**. Examples include tsetse flies which transmit **trypanosomiasis** (sleeping sickness) and ticks which transmit both heartwater and redwater diseases.

Parasites also cause damage and diseases to their hosts. But unlike pests which affect their hosts only upon visiting the hosts, parasites establish permanent physiological relationships with their hosts. They live either on or in their hosts. The hosts are normally bigger organisms than the parasites and the two belong to different species. Whilst living on or in their hosts, parasites feed on their tissues and partly digested food of their hosts. They also release their excretory products directly into the bodies of their hosts causing various diseases.

The pests and parasites menace is a worrying continuous natural occurrence. A sound knowledge of their life cycles is therefore a prerequisite for their effective prevention and control. Their life cycles show all the reproductive events and structural changes that occur from one generation to another including the stages when they are most destructive and most vulnerable for destruction to break the cycle.

Types of pests and parasites of plants

True parasitic plants that commonly infest plants in tropical Africa include **mistletoe**, **dodder** and **cassytha**. These parasites grow on or in host plants from which they obtain nourishment harming the host in the process.

Mistletoe

There are two main types of mistletoe. These are the **Broadleaf mistletoe** (*Phoradendron macrophyllum*), an evergreen parasitic plant which grows on a number of ornamental trees; and the **Dwarf mistletoe** (*Arceuthobium* spp.) which mainly infest pines and conifers.

Mistletoe generally has green stems and thick leaves which are oval in shape. An entire plant develops a rounded form that is about 60 cm in diameter (Figure 3.16)

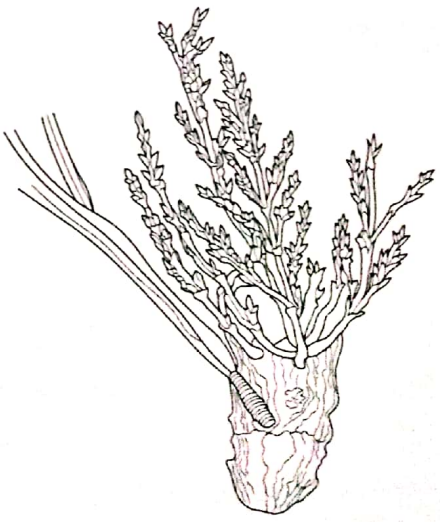


Fig 3.16 Dwarf mistletoe

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Using their specialised root system called **haustorium**, mistletoes absorb both water and nutrients from their host trees. This often weakens the hosts, stunts growth or kills them especially if they are stressed by drought or disease. Some mistletoe also causes their host plants to develop galls around the site of infestation.

Mistletoe may be controlled by

- pruning and removing infested plant parts
- planting tree species that are resistant to mistletoe infestation
- spraying the pesticide and plant regulator called **ethephon**.

Dodder

Dodder or witches' hair (*Cuscuta* spp.), is a parasitic annual plant which infests many ornamentals, crops and even weeds. Table 3.6 is a list of some vegetable crops and ornamental plants that are susceptible to dodder.

Table 3.6 Common vegetable and ornamental plants susceptible to dodder infestation

Vegetable crops	Ornamental plants
carrots	petunia
garlic	periwinkle
melons	morning glory
eggplant	chrysanthemum
onion	english ivy
pepper	
tomato	
sweet potato	

Dodder plants have thread-like or slender twining stems. The stems vary in colour ranging from pale green to yellow to bright orange. The flowers are small, cream-coloured and bell-shaped usually occurring in clusters (Figure 3.17)

Dodder is an obligate parasite because its stem is non-photosynthetic since it has no chlorophyll. It is completely dependent on its host for nutrients and water. This, it does by using its modified root system (haustorium) to penetrate the stem of the host and tap its nutrients. Dodder is tolerant to brackish water and can therefore infest salt marshy plants along coastal estuaries. The effects of dodder infestation may be moderate but in some severe cases it can cause stunted growth, loss of vigour or death.

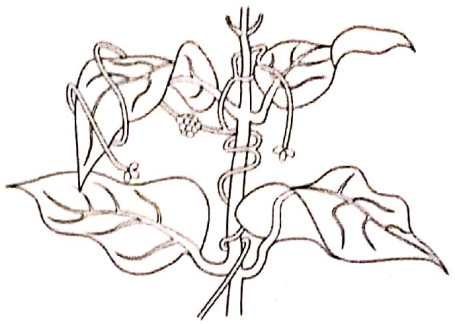


Fig 3.17 Dodder

Effective management of the incidence of dodder requires control of current population, prevention of the production of dodder seeds and the suppression of new seedlings in subsequent years. These, in turn, require the use of

- dodder-free seeds
- clean equipment and clothing
- non-host plants
- burning to reduce dodder infestation
- pruning of infested plant parts.

Cassytha

Cassytha is a parasitic vine and native to Australia with a few species in Tropical Africa such as **Cassytha ciliolate** in South Africa. It has a striking superficial resemblance to dodder even though the two do not belong to the same family. Cassytha is the sole parasitic member of the family **Lauraceae** whereas dodder belongs to the **Convolvulaceae** family.

Cassytha has a wide host range including even coastal plants. Its infestation reduces photosynthesis and vigour in the host plants. It also causes stunting and death of plants.

Crop weevil (*Sitophilus* spp.)

Crop weevils are major pests of grains in storage but they also infest crops in the field if harvesting is delayed. Common examples of grain weevils in West Africa are rice weevil (*Sitophilus oryzae*), maize weevil (*Sitophilus zeamais*) and cowpea weevil (*Callosobruchus maculates*) (Figure 3.18).

Life cycle

The adult female bores into the grain, lays hundreds of eggs for about a week and seals the hole with a sticky

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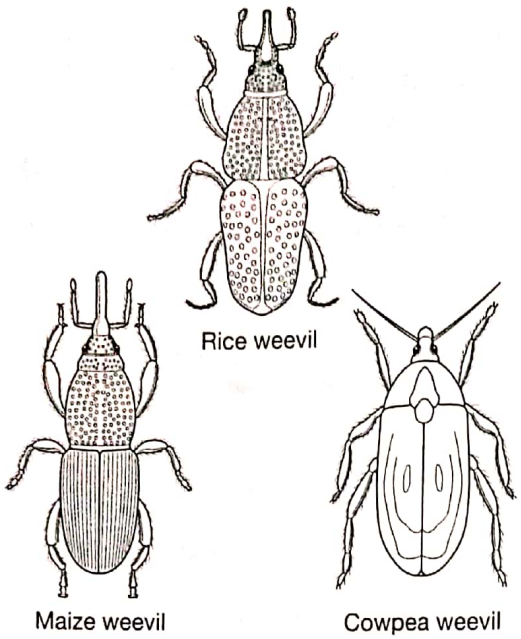


Fig 3.18 Some grain weevils.

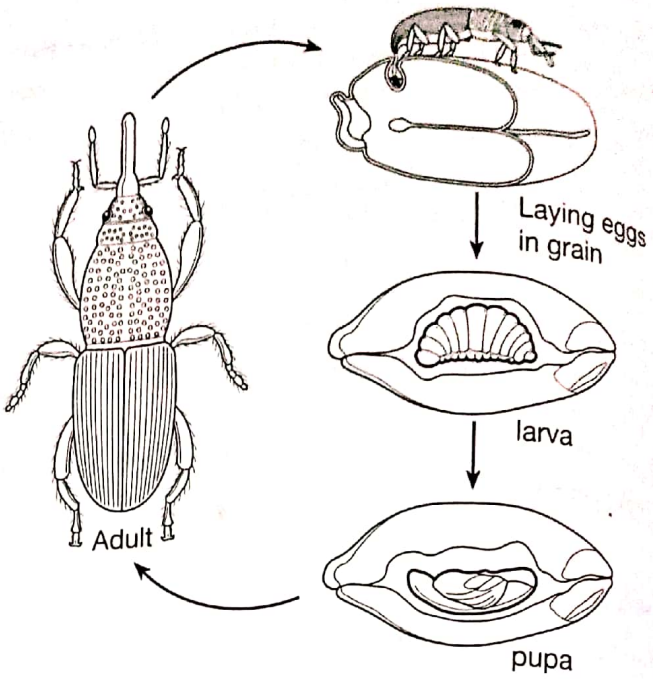


Fig 3.19 Life cycle of a crop weevil.

secretion. The eggs hatch after 3 days into larvae. The larvae go through 4 stages called 'the four larval instars' in a period of 2 to 5 weeks to form the pupae. Pupation takes 5 to 15 days for the adults to emerge which live for about 8 months (Figure 3.19)

Under favourable conditions a generation is completed in less than 4 weeks.

Damage

The damage caused to grains include surface eating of the grain, boring into the grain and eating the kernel and reducing the grains into powder in severe infestation.

Types of pests and parasites of farm animals

Parasites that live on the outside of their host's body are called **ectoparasites**; and those that live within the host are **endoparasites**. The most common ectoparasites of livestock in West Africa are ticks.

Ticks

Ticks (Figure 3.20), in addition to sucking the blood of their hosts and causing body irritation, also act as vectors of disease. Ticks need one, two or three hosts in order to complete their life cycle:

- In **one-host ticks** the larval, nymphal and adult forms of the tick all feed on one host, e.g. *Boophilus* spp.
- In **two-host ticks** the larval and nymphal forms feed on one host and the adult tick feeds on another host, e.g. *Rhipicephalus* spp.
- In **three-host ticks** each of the larval, nymphal and adult forms of the tick feed on a different host, e.g. *Hyalomona* and *Demacentor* spp.

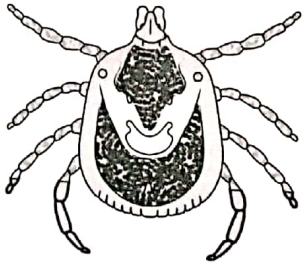


Fig 3.20 A cattle tick.

The life cycle of a three-host tick is as follows:

1 Eggs laid on ground; larvae hatch and climb on to first host, where they feed on blood.
2 Engorged larvae drop to ground and moult; nymphs emerge.
3 Nymphs climb on to second host and feed on blood.
4 Engorged nymphs drop to ground and moult; adults emerge.
5 Adults climb on to third host, feed on blood and mate.
6 Engorged females drop to ground and lay eggs.

Ectoparasites are generally controlled by avoiding overcrowding in animal pens, practising rotational

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grazing, spraying or dipping farm animals with recommended chemical compounds, and dusting with powdered pesticides in the case of poultry. Ticks can be controlled by handpicking them from the animal (deticking) and burning them. It is important to wash the hands after this to avoid disease transmission.

Worms

Parasitic worms are all endoparasites living in the tissues and organs of their hosts and feeding on blood or partially digested food. Besides causing body irritation, emaciation and anaemia they also cause constipation and constrict the alimentary canal if in large numbers.

Worms are controlled mainly through regular deworming of the infested animals with recommended dewormers such as Piperazine. Good feeding and the avoidance of grazing on wet pastures also control worm infestation in livestock.

Liver flukes

The liver fluke (*Fasciola hepatica*) is an endoparasite that lives mainly in the liver of its host. It causes the disease called fascioliasis in cattle, but sheep are its main victim. Sheep and cattle with chronic liver fluke infection soon die.

Liver fluke infestation is common in the wetter parts of West Africa. This is because the life cycle of the fluke involves an intermediate host snail which requires a permanent water source (Figure 3.21).

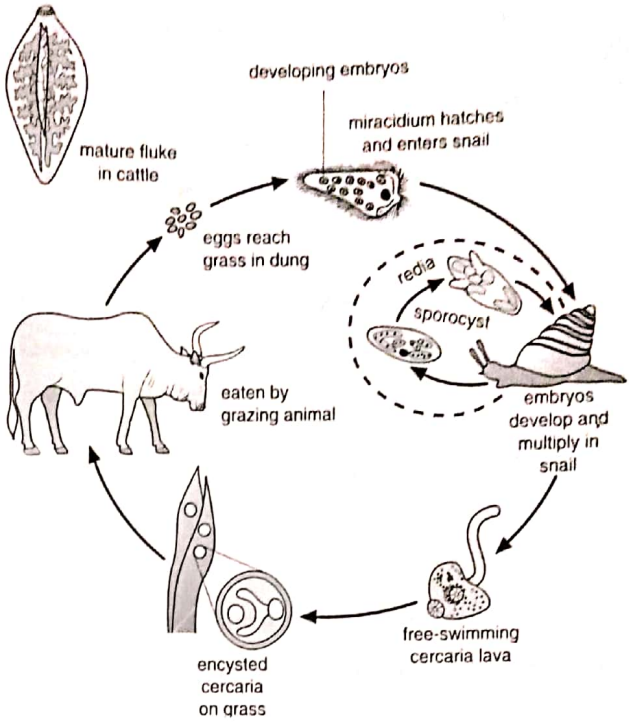


Fig 3.21 Life cycle of the liver fluke (*Fasciola hepatica*).

Pests and parasites of humans and their diseases

Malaria

About 200 million people get malaria in tropical countries every year, and about 2 million die of it. Malaria is caused by a single-celled organism called *Plasmodium*. It is spread by the female of the *Anopheles* mosquito.

Method of transmission

Plasmodium lives in the salivary glands of an infected female *Anopheles* mosquito. The mosquito feeds on human blood. When it bites in order to take a blood meal, the saliva enters the bloodstream taking the parasites with it. They are carried to the liver where they enter the cells, feed and multiply rapidly. Later the parasites invade the bloodstream and enter the red blood cells. Inside the red cells, *Plasmodium* grows again and reproduces. The new parasites then break out, destroying the red cells and producing poisonous substances. This causes very high fever and sweating. Eventually the fever passes but keeps returning for as long as the parasite remains in the body. Next time the infected person is bitten by a mosquito, some of the parasites are taken into the mosquito's stomach. Here they continue to multiply. They break through the stomach wall and pass in the bloodstream to the salivary glands. They wait here until they are passed on to the next healthy person the mosquito bites. The life cycle of the parasite is shown in Figure 3.22.

Symptoms

A typical attack of malaria has three stages. It begins with a feeling of being cold, a headache and weakness. There is shivering for 15 minutes to 1 hour. This is followed by very high fever, often 40°C or more. The person is weak and sometimes not in his or her right mind. The fever may last several hours or days. Then the person begins to sweat as his or her temperature drops. People who have malaria often and over a long period may develop an enlarged spleen and anaemia. Anyone

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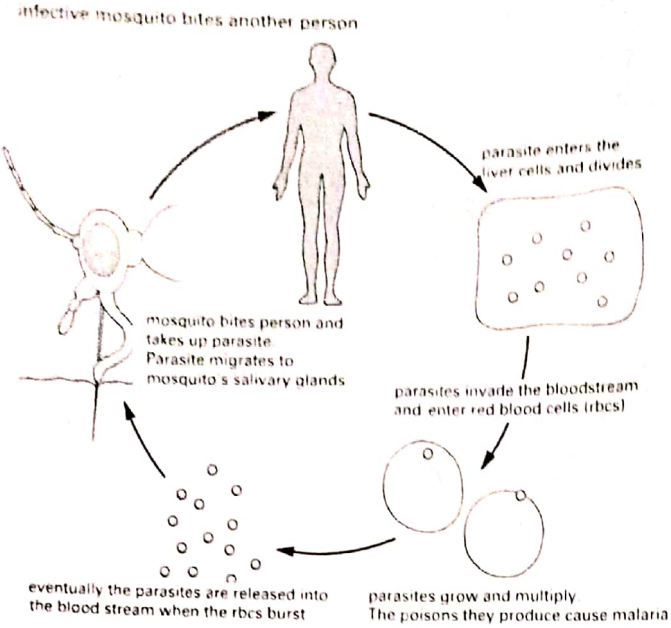


Fig 3.22 Life cycle of the malarial parasite, *Plasmodium*.

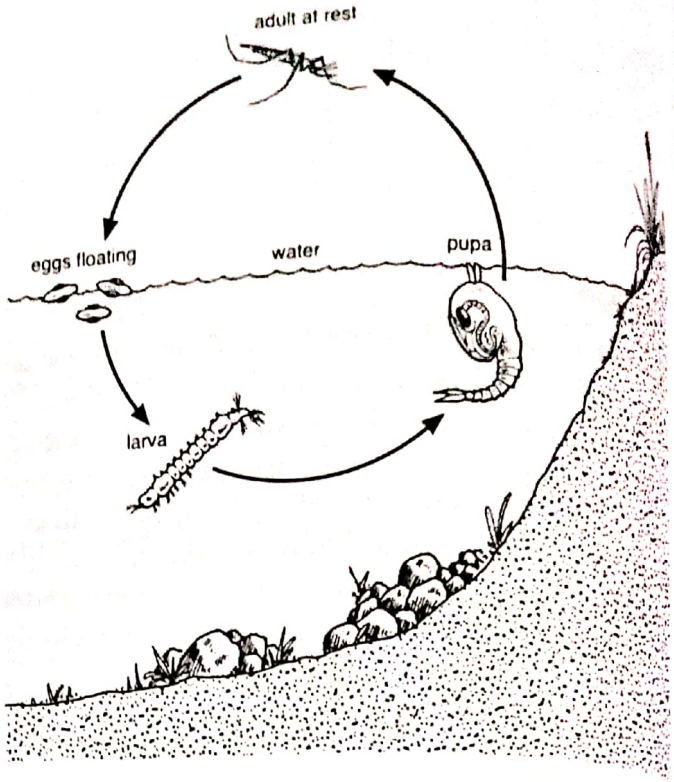


Fig 3.23 The life cycle of the *Anopheles* mosquito.

who suspects they have malaria or suffers from repeated fevers should report to a health centre.

Control and prevention

Malaria can be controlled if everyone cooperates. Many control measures involve breaking the life cycle of the mosquito (Figure 3.23). All measures should be practised at the same time.

- One method is the destruction of the mosquito. The adults can be killed by spraying surfaces on which they may settle with benzene hexachloride (BHC) or dieldrin. Aerosol sprays may be used to kill them in homes. It is best to use those which do not contain chlorofluorocarbons (CFCs). The larvae and pupae (young) can be destroyed by spraying oil on the surface of pools and marshes where mosquitoes breed. The oil lowers the surface tension of the water, causing the larvae and pupae to sink and drown.
- Fish such as top minnow can be introduced into the water to feed on the larvae and pupae.
- The breeding grounds can be drained.
- Mosquitoes can be prevented from biting people. This can be done by sleeping behind mosquito nets and covering windows with a fine-mesh screen to keep them out. Wearing long-sleeved shirts and trousers in the evenings will also prevent bites on arms and legs. Bites may also be prevented by smearing repellent creams on exposed skin.
- Taking regular weekly doses of preventive drugs such as daraprim and paludrine.

Treatment

Malaria is treated with drugs such as chloroquine, fansidar and camoquine. Unfortunately, the parasite has developed resistance to some of these drugs. A trained medical worker's advice should therefore be sought before taking any drugs.

Amoebiasis (amoebic dysentery)

This is caused by a single-celled microscopic organism called *Entamoeba histolytica*. It is spread by houseflies, food and water contaminated with faeces, and person-to-person contact.

Method of transmission

The parasite lives in the large intestines of human beings where it feeds and multiplies. Sometimes the parasites irritate the intestines, producing inflammation (infection with swelling, pain, heat and redness). When *Entamoeba* passes out in faeces, it develops a cyst (a resistant coat) around itself. In this form, it can remain alive for a considerable period of time. The cyst is spread by flies and by water and food contaminated with faeces. Eventually, the cyst passes into a healthy person and the parasite's life cycle is repeated (Figure 3.24).

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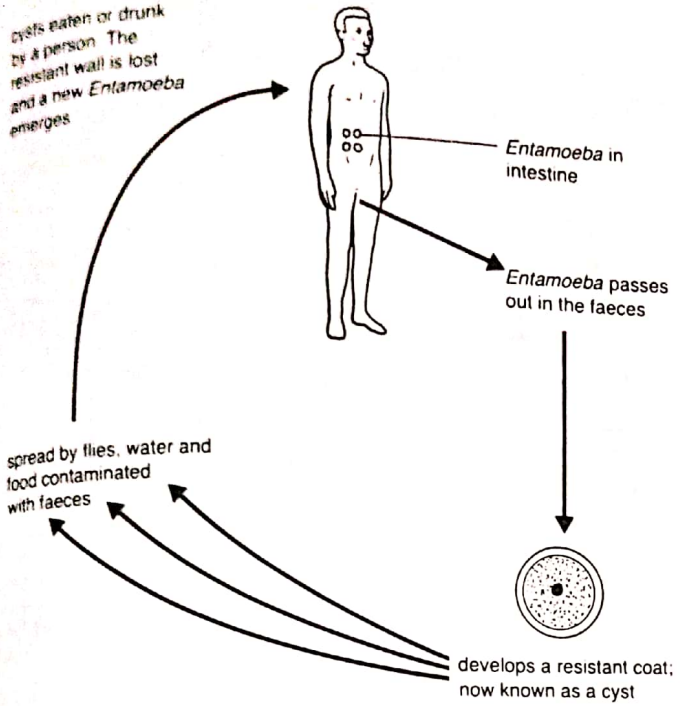


Fig 3.24 The life cycle of *Entamoeba histolytica*.

Symptoms

Typical symptoms are painful muscular contractions in the gut and a feeling that one needs to visit the toilet frequently, even when little or nothing (or just mucus) comes out. The faeces contain lots of mucus and are sometimes stained with blood. In severe cases there is a considerable amount of blood in the stools and the person is very weak and ill. Usually there is no fever. It may be necessary to have a stool test to confirm the disease, since bloodstained diarrhoea may have other causes.

Control and prevention

Amoebic dysentery is prevented by the following methods:

- Food should be kept away from flies and cockroaches.
- Infected persons should not handle food.
- Water sources must be protected from contamination with faeces.
- Faeces should be properly disposed of.
- Drinking water must be well purified.
- Personal hygiene habits such as washing of hands should be enforced.

Treatment

The disease is treated with drugs such as tetracycline and emetine. Medical advice should always be sought.

Worm diseases

A large number of parasitic worms can cause human diseases. The life cycle of the worms is usually complicated. Often there are two hosts – a person as the primary host and some other animal as the secondary host. The parasite becomes sexually mature in the primary host. The secondary host is that in which the asexual stages of the parasite occur.

Dracunculiasis (Guinea worm disease)

This disease is caused by a parasitic worm, *Dracunculus medinensis* (Guinea worm). It is one of the oldest parasitic human diseases. It is a water-borne disease which occurs in rural areas where people get their water supply from sources such as lakes, ponds and rivers. The water is often contaminated with Guinea worm larvae. The method of transmission is summarised in Figure 3.25.

Guinea worm disease is recognised by the presence of a painful blister, usually on the skin of the leg or arm. The blister bursts and forms a sore from which a long female worm slowly emerges. People do not usually die from the disease, but for about three months while the disease lasts, the victim suffers pain and weakness and is unfit to carry out normal daily activities. This affects normal life in the following ways:

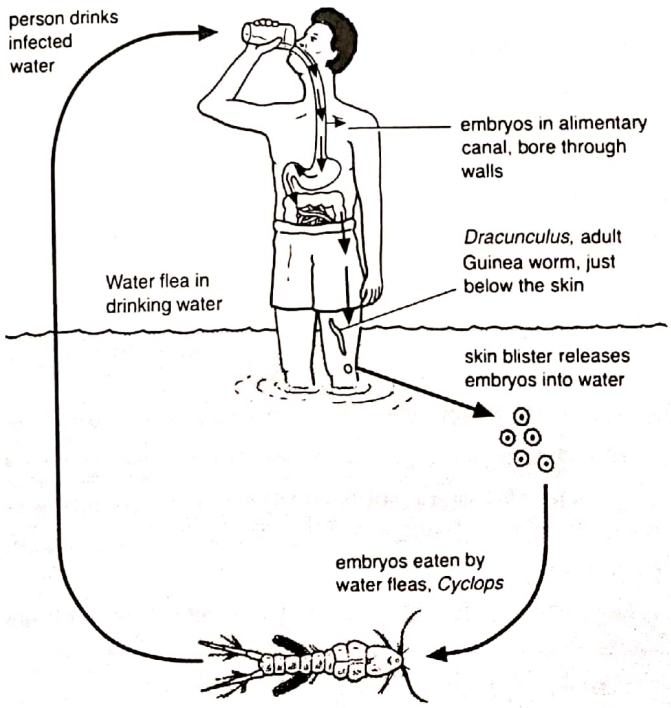


Fig 3.25 The life cycle of the Guinea worm, *Dracunculus*.

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- Family life is disrupted. Affected mothers are unable to take care of the children, prepare food or do other household jobs. Farming activities come to a stop, causing a loss in the family income.
- Children who are affected are unable to go to school. Sometimes so many pupils stay away from school that the schools have to be closed.
- Other serious infections such as tetanus can occur because germs can enter the open sore caused by the worm.

Guinea worm can be prevented by the following methods:

- Safe water sources should be provided. These include wells and boreholes.
- People suffering from the disease should not bathe in drinking water.
- Drinking water should be obtained from sources which are free from Guinea worm larvae.
- Water from unsafe sources should be filtered and boiled before drinking.
- All members of the community must work together to protect the water supply from all harmful practices.

The Ghana Guinea Worm Eradication Programme is working to eradicate the disease from the country.

There is no treatment for Guinea worm disease. Once a person is infected, the disease will run its normal course. However, antibiotics are sometimes used to treat the sore left after the worm has come out of the body. Drugs such as Paracetamol and aspirin are used to help relieve the pain of the swelling. The worm can be pulled out before it dies in the body by attaching a thread to the worm or rolling it round a matchstick and pulling gently, a little more each day.

Schistosomes

These parasites cause the schistosomiasis disease of humans commonly called Bilharzia. The major symptom of the disease is the expulsion of bloody urine of infected persons. Common examples of schistosomes in tropical Africa are *Schistosoma mansoni* and *Schistosoma japonieum*.

The life cycle of the schistosome involves an intermediate host, the water snail, in which a number of asexual reproductive stages occur; and a definitive host (e.g. human) where the parasite undergoes sexual reproduction (Figure 3.26):

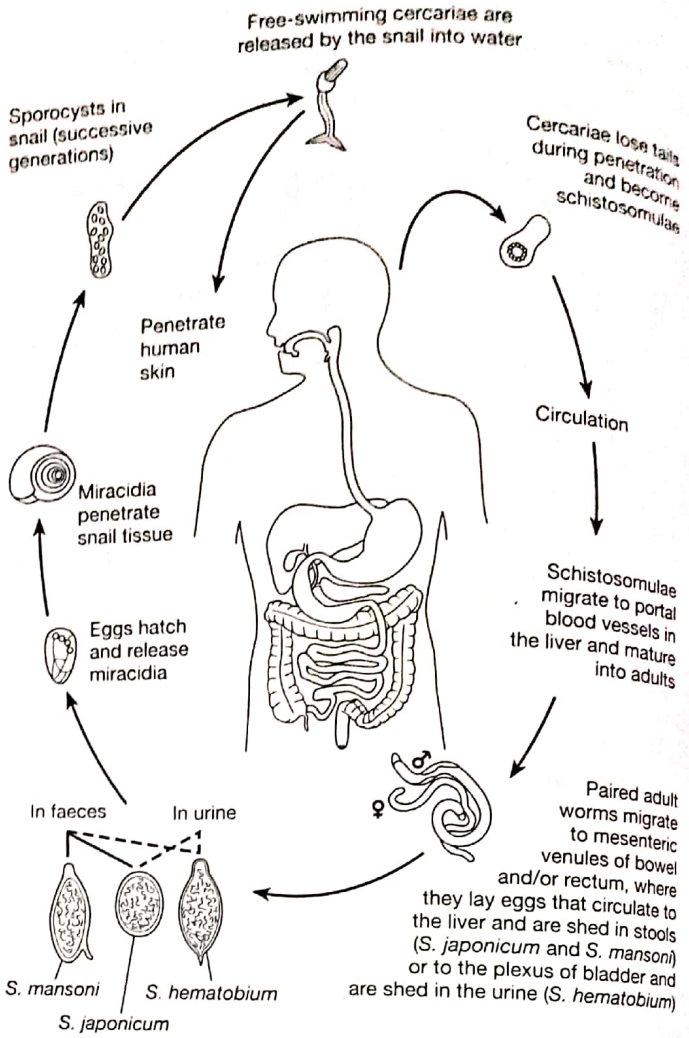


Fig 3.26 Life cycle of *Schistosoma mansoni*.

1 Eggs of schistosomes in water hatch releasing miracidia.
2 Miracidia penetrate the tissue of fresh water snails and enter the sporocyst stages.
3 Miracidia hatch into cercariae in the snail and are released into water for them to swim freely.
4 The cercariae penetrate the skin of man and transform into endoparasitic larvae called schistomules.
5 Within 5 to 7 days of penetration the schistomules enter the venous circulation and finally migrate to the lungs.
6 They then travel through the circulatory system to the hepatoportal circulation after 15 days where they mature and mate.
7 The schistosomes migrate to their final sites either in the bladder or the intestine where the females begin egg laying.
8 The eggs are attached to the walls of the lumen which they later penetrate.
9 Eggs are expelled in urine or faeces.

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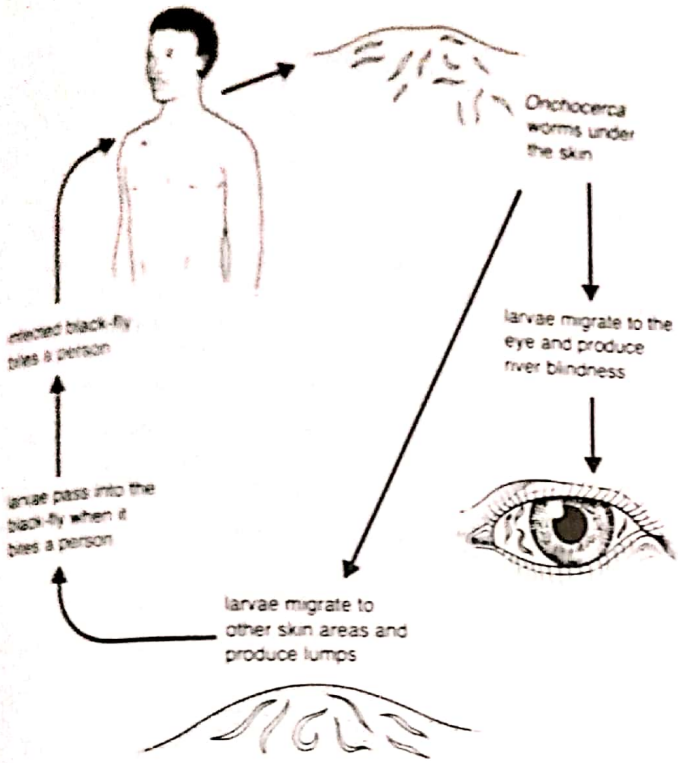


Fig 3.27 The life cycle of *Onchocerca*.

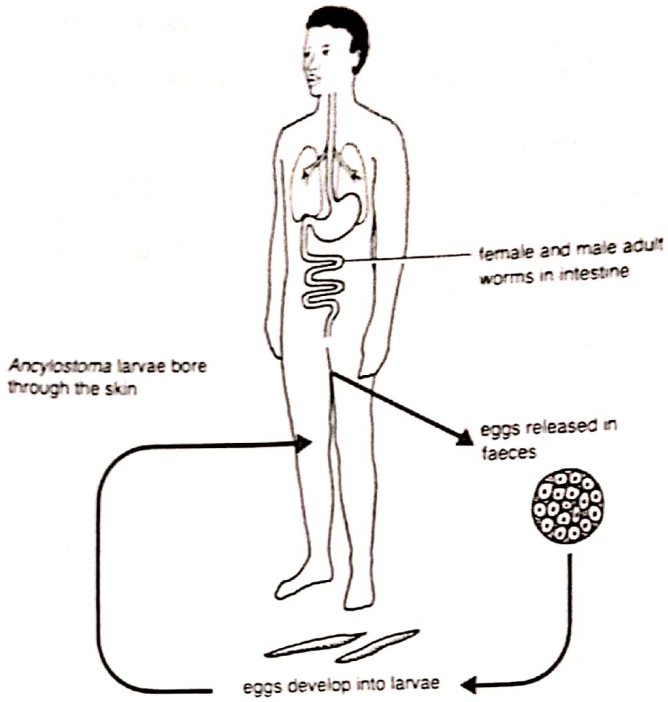


Fig 3.28 The life cycle of *Ancylostoma duodenale*, the hookworm.

10 The miracidium liberated from the eggs enter snail hosts and eventually released as cercariae that seek human hosts.

Table 3.7 describes other diseases caused by worms.

Tsetse fly

Trypanosoma brucei, the protozoa that cause the **trypanosomiasis** disease, is carried by tsetse flies. This parasitic disease, commonly called **sleeping sickness**, affects both animals and man. It is thus a zoonotic disease. The tsetse flies, which are the parasitic or immediate hosts, are large and brown. They require heavy shade and high relative humidity for breeding. This explains why their population is high in the forest zones of West Africa.

Life cycle

The tsetse fly bites a mammalian host, sucks blood and injects the parasites called **trypomastigotes** into the tissue of the host's skin. The parasites enter the lymphatic system of the host and continue into the bloodstream. From the bloodstream, the trypomastigotes are carried to other sites like the lymph and spinal fluids where they undergo replication through binary fission.

Meanwhile, if the blood sucked by the fly contains **trypomastigotes**, they multiply and metamorphose into **epimastigotes** which move into the fly's salivary glands and continue replicating by binary fission in readiness to infect another mammalian host (Figure 3.29).

The trypanosomiasis disease exists in two forms depending on the mammalian host and the parasite. One form, the human trypanosomiasis is caused mainly by *Trypanosoma brucei gambiense*; and the other, the animal form (Nagana) is caused by *Trypanosoma brucei rhodesiense*.

Symptoms

The symptoms of trypanosomiasis begin with fever, headaches, joint pains and swelling of the lymph nodes. If allowed to progress, the disease gradually breaks down the defences of the infected person or animals with new symptoms including anaemia, cardiac, endocrine, and kidney disorders and diseases.

The second and final phase of the disease has symptoms including the following in order of progression:

- reduced body coordination
- extreme fatigue
- daytime slumber
- night-time insomnia (inability to sleep)
- mental deterioration leading to coma and death.

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Table 3.7 Other diseases caused by worms

Disease	Cause	Method of transmission	Symptoms	Control/prevention and treatment
onchocerciasis (river blindness)	*Onchocerca volvulus*	Larvae of worms are introduced into a person's skin by the bite of the *Simulium* fly (black fly) (Figure 3.27).	Painless lumps appear on the skin; intense skin itching; gradual thickening and wrinkling of skin; eye trouble leading to blindness.	• bush and vegetation at banks of fast flowing streams should be cleared • breeding grounds (fast flowing streams) are sprayed with insecticide from aircraft • don't sleep outside Drugs such as suramine are used for treatment but need careful administration.
elephantiasis (filariasis)	*Nuclei* (a filarial worm)	Mosquito, especially the *Culex* species, suck up larvae of parasites in blood when it bites an infected person. Larvae are introduced into the blood of another person during the next blood meal. The larvae grow and reproduce in the lymph vessels.	Inflammation of lymphatic vessels; headaches; thickened and cracked skin; swelling of legs due to blockage of lymph vessels by worms.	Mosquito control and prevention as for malaria. A cure is difficult so prevention is important.
ascariasis (roundworm)	*Ascaris lumbricoides*	Adult worm (20–30 cm long) lays eggs in the small intestine. These pass out in faeces into soil and may come to lie on vegetables and other field crops. The larvae enter the alimentary canal when the eggs are swallowed.	Indigestion; general body weakness; large, swollen belly in children.	• protect food from flies • wash vegetables well, for example in potassium permanganate solution, e.g. before eating • observe personal hygiene, e.g. washing hands after visiting the toilet Mebendazole will usually get rid of roundworms.
hookworm	*Ancylostoma duodenale*	Adults, about 1 cm long, live in the small intestine attached to the wall. Eggs pass out in faeces and hatch in soil into larvae; penetrate skin into bloodstream and eventually pass into the small intestine (Figure 3.28).	Tiredness; acute anaemia.	• proper use of latrines • protection of food from flies • proper disposal of faeces • wearing shoes or sandals Drugs such as Bephimium will kill adult worms in the intestine.

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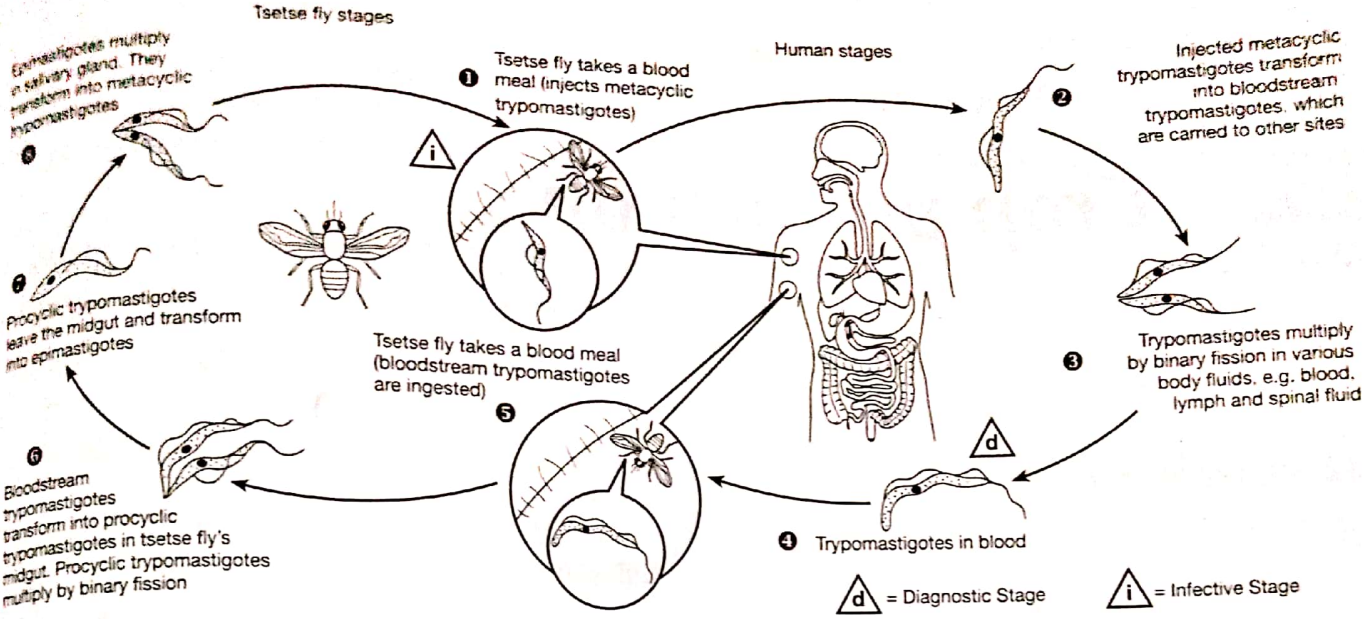


Fig 3.29 Life cycle of *Trypanosoma*.

Prevention and Control

Both prevention and control measures of the disease are focused in the parasitic host and vector, the tsetse fly. The measures are as follows:

- Prophylaxis and monitoring, case detection and treatment through intravenous injection.
- Disruption of the life cycle of tsetse flies to reduce their number.

Self check

For questions 1 to 8, choose the letter that refers to the correct option.

1 Which of the following parasites of livestock has two or three hosts?
A tapeworm B roundworm
C tick D louse

2 Which of the following symptoms is characteristic of schistosomiasis?
A cataract B blood in urine
C chest pains D constipation

3 Sleeping sickness is the common name for
A schistosomiasis B trypanosomiasis
C onchocerciasis D filariasis

4 Which of the following plants are NOT parasitic?
A Cassytha B Centroscema
C dodder D mistletoe

5 *Callosobruchus maculatus* is the scientific name for
A cowpea B rice weevil
C yam borer D cotton stainer

6 Both heartwater and redwater diseases are transmitted by
A worms B ticks
C fleas D lice

7 The following are all causes of non-pathogenic diseases except
A stress B malnutrition
C mistletoes D viruses

8 Daytime slumber is a symptom of an advanced stage of
A trypanosomiasis B schistosomiasis
C onchocerciasis D elephantiasis

9 Distinguish between the following pairs of terms
(i) Pests and parasite
(ii) Endoparasite and ectoparasite
(iii) Infection and infestation.

10 Discuss the parasitic plant dodder under the following headings:
(i) Morphology
(ii) Susceptible plant
(iii) Damage caused
(iv) Prevention and control.

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2 Crop production

Learning objectives

After studying this unit, you should be able to:

1 describe general principles of crop production
2 cultivate a crop up to harvesting stage.

Background information

The term 'crop' refers to plants which are deliberately cultivated and gathered for human use. Crop plants may be classified into groups based on their **uses**, **botany**, **life cycle**, **climate** or **methods of cultivation**.

Based on their **uses** crops are grouped into

- **cereals** (e.g. maize, rice, millet, sorghum)
- **legumes** (e.g. cowpea, groundnut, soybean)
- **roots** and **tubers** (e.g. cassava, yam, potatoes)
- **edible fruits** and **nuts** (e.g. pineapple, pawpaw, citrus, banana, mango cashew)
- **beverage crops** (e.g. coffee, cocoa, tea)
- **oil crops** (e.g. oil palm, coconut, groundnut, shea butter tree)
- **fibre crops** (e.g. cotton, kenaf, jute, sisal)
- **vegetables** (e.g. pepper, onion, okro, tomatoes)
- **forage crops** (e.g. forage legumes and grasses)
- **industrial crops** to be used as industrial raw materials (e.g. sugar cane, cotton, tobacco, etc.)
- **ornamental crops** (e.g. sunflower, begonia, roses).

The reference to crops as **annuals**, **biennials**, **perennials**, or **permanent crops** is based on their life cycle. **Annual crops**, also known as **arable crops**, grow, reproduce and die within one year or growing season. Crops that have a two-year life span are the **biennials** and those that last for 3 to 5 years are the **perennials**. Yet another group of crops that last for 10 to 30 years, as most plantation crops do, are commonly called **permanent crops**.

Among the many uses of crop plants are the following:

- **Food** – Crop plants that produce food for human consumption are referred to as **food crops**. A food crop that is in constant demand and use by a community of people because of its recognised quality becomes a staple food crop in that community. Common **staple food crops** in West Africa include maize, millet, cowpea, groundnut and rice. Others are yam, cassava, plantain and local vegetables.
- **Animal feed** – Animal feed is largely vegetative in nature consisting forage legumes and grasses such as centrosema, guinea grass, stylosanthes, etc. and hay and silage. Most food crops are also consumed by farm animals. These include roots and tubers such as cassava as well as cereal and leguminous grains often compounded into concentrates.
- **Clothing** – Fibre crops such as cotton are used in making clothing, bags, etc. for humans. The cotton is first used in a textile factory to make threads of various types which are in turn used to make clothing.
- **Drugs** – In West Africa intensive use is made of the leaves, stems, roots and even fruits of different plants to prepare herbal drugs used in curing several human diseases.
- **Shelter** – Grasses and the leaves of crop plants such as oil palm and coconut are important thatch roofing materials. Tree stems and wood obtained from them are useful building materials.
- **Ornamentals** – Ornamental crops by virtue of the decorative appeals and 'sweet' scents are planted in human residential areas as flowers or hedges to create beautiful and pleasant scenery.

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- **Raw materials** – Several crops are cultivated at plantation level and used to feed agro-industries for manufacturing many useful products. They include cocoa, sugar cane, tobacco, etc.

General principles of crop production

Principles of crop production are guiding rules which should be followed in the crop production cycle to ensure the efficient control of factors necessary for healthy and optimum growth, development and yield of crops. These factors include temperature, sunlight, moisture, air, soil, quality nutrients and correct pH, and pests and diseases.

The production cycle of crops consists of the following four distinct activities:

- pre-planting activities
- planting activities
- post-planting activities
- harvesting and post-harvest activities.

These will be described in the following sections.

Pre-planting activities

These refer to all activities that are carried out in respect of the planting materials and on land before the crop is planted. They include the selection of appropriate crop varieties for cultivation, site selection and land preparation.

Selection of appropriate crop varieties

A crop variety is a group of crops that have been favourably modified by artificial selection making them different from other members of the species to which they belong. The modification is normally minor but permanent and transmissible. Thus there may be several crop varieties under one species and several species under one genus of crop plants.

For example **maize** (British) or **corn** (American) is botanically called *Zea mays*, where **zea** is the generic name and **mays** the species name. Today, in Ghana, there are maize varieties such as Dobidi, Obaatampa and Okomasa under the species **mays**. Maize varieties such as Lagos White, Calabar Local and Bendel Local are found in Nigeria. Thus a comprehensive botanical classification of the Obaatampa maize variety, for example, is outlined below:

Kingdom	:	Plantae
Division	:	Spermatophyta
Sub-division	:	Angiospermae
Class	:	Monocotyledonae
Family	:	Graminae
Genus	:	*Zea*
Species	:	*Mays*
Variety	:	'Obaatampa'

The selection of appropriate varieties of crops for cultivation is guided by factors such as:

- soil requirements of crop variety (nutrients, moisture, ph, texture, structure and depth)
- climatic conditions (i.e. temperature, sunlight, rainfall, wind)
- drought tolerance
- resistance to lodging
- resistance to pests and diseases
- adaptation to different elevations
- day length sensitivity
- maturity period
- yield potential
- growth habits
- consumer preferences (market).

Crop varieties that are appropriate and should be selected for cultivation are those that are favoured by most of these factors. Such crop varieties if cultivated under good cultural practices give high yields and profits.

Site selection

The selection of a suitable site for crop cultivation is influenced by factors such as those outlined below:

- **Soil type** – Soil properties such as moisture content, fertility, pH, structure and texture greatly influence the growth of crops. Most crops, however, do well in sandy loam soils that are neutral to alkaline in pH. Only a few crops, such as rice and sugar cane, do well in acidic soils.
- **Climatic conditions** – Climatic factors such as temperature, rainfall, sunlight and wind all affect crop production but to different degrees. In West Africa, rainfall intensity and distribution is the most crucial factor. Temperature, sunlight and wind are not significantly limiting. Tree crop such as cocoa, oil palm, citrus, coffee and rubber flourish better in the forest zones which are characterised by relatively

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high intensity and fairly good distribution of rainfall. Yam, cassava, cereals and legumes perform well in the forest-savannah transitional and savannah zones.

- **Topography** – The preferred site for crop cultivation is one that has a level or gently sloping topography. Such lands can easily be tilled mechanically and have low incidence of soil erosion. In areas where lands are generally sloppy, soil conservation practices such as strip cropping, contour ploughing and terracing are necessary.
- **Source of water** – Siting the farm close to a reliable source of clean water, such as rivers, streams, ponds, wells or boreholes, is highly recommended. This will help to easily increase and sustain soil moisture content for optimum crop growth through supplementary irrigation or watering in periods when rainfall is erratic and inadequate. Vegetable crops which require regular watering throughout their growth periods are also successfully grown in such areas.
- **Accessibility to farm** – A farm is said to be accessible if it can be reached easily and quickly as a result of good roads and proximity. Farm inputs and farm produce respectively are easily transported to and from such farm sites.
- **Labour availability** – Large-scale farming may be periodically labour-intensive as is the case during planting, weeding and harvesting. It is therefore a good practice to locate a farm where cheap casual labour is available for such activities.
- **Market** – Commercial crop production is aimed, ultimately, at making profits through ready markets for the farm produce. Siting a farm, especially one that produces perishable produce, near readily accessible markets is an excellent entrepreneurial decision.

Land preparation

Land preparation involves land clearing, soil tillage and seedbed preparation.

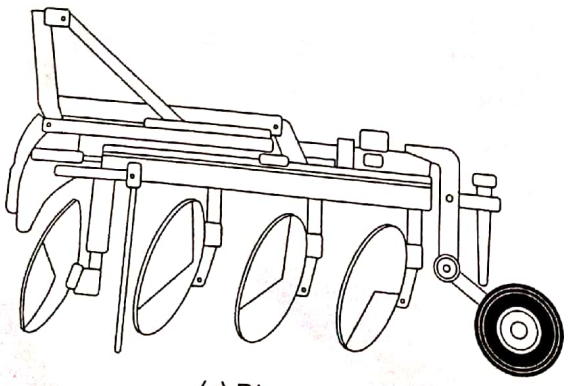
Land clearing

Land clearing is the manual or mechanical removal of vegetation cover from the land. This paves the way for tillage practices and subsequently for the planting of crops. In the forest areas the underbrush is cut and the trees chopped down leaving a few to provide shade. In the savanna very little clearing is required. Plant debris is then cleared, often by burning. Tree stumps are then removed if the land is to be ploughed and ridged.

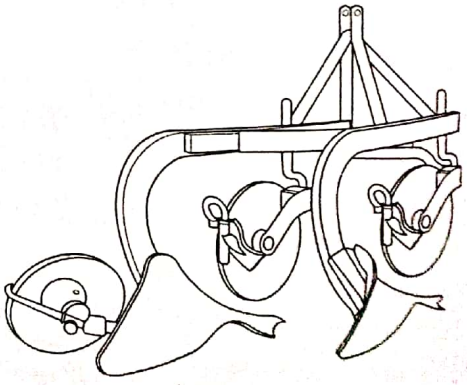
Soil tillage

Soil tillage is the physical manipulation of the soil to optimise conditions favourable for seed germination and for seedling emergence and establishment. Soil is the main medium of crop cultivation. It must therefore be well prepared to improve its productivity. Soil tillage is one of the major activities that are carried out in preparing the soil. It creates optimum environmental conditions for plant growth. During tillage the soil surface is broken up, the soil stirred and turned and the surface conditioned to an appreciable depth. The initial breaking of soil is called primary tillage and subsequent operations undertaken to break down soil clods through harrowing and to prepare the seedbed for planting are known as secondary tillage practices.

Primary tillage (ploughing) can be done manually using an Indian hoe or the native hoe; or mechanically using a tractor-driven disc plough or mouldboard plough (Figure 3.30)



(a) Disc



(a) Mouldboard

Fig 3.30 Ploughs

Generally soil is tilled to achieve the following objectives:

- to improve soil structure
- to facilitate the infiltration of water into the soil and its percolation in the soil
- to enhance root penetration
- to destroy the larvae and pupae soil-borne crop pests by exposing them to the sun
- to clean the soil of stubble and by burying vegetation in the soil
- to mix fertiliser or organic manure into the soil
- to increase soil aeration leading to microbial activities
- to control weeds by dislodging them and exposing their roots to the hot sun or by simply burying them mechanically
- to level the soil surface for mechanical sowing
- to control soil erosion by both water and wind.

Seedbed preparation

A seedbed is a place where seeds germinate and from which established plants derive nourishment and support through their roots.

Seedbeds with mounds and ridges perform similar functions in crop production. They increase the depth of surface soil, provide good drainage especially in water-logged areas and limit soil erosion. They also provide a basis for adequate supply and retention of soil water and for the expansion of root and stem tubers of crops. In West Africa mounds are usually made manually using native hoes but ridges are made using a tractor-driven implement called a ridger. Mounding and ridging are the terms used for the making of mound and ridges respectively.

It is, however, important for students to note that sometimes an entire ploughed and finely harrowed farmland can serve a seedbed, especially when soil moisture is adequate and there are no drainage problems. This is the case when crops such as maize, cotton, rice, cowpea and soybean are to be cultivated. In vegetable production, seedbeds are generally raised and rectangularly shaped.

A good seedbed should have the following characteristics:

- its surface soil should be fine and granular
- it should be firm underneath to ensure satisfactory movement of moisture to sown seeds
- it should retain adequate moisture but porous enough to ensure good aeration and drainage
- it should be free from weeds and weed seeds

Planting activities

Methods of propagation and planting methods

Plant preparation is the process of regeneration of plants from either their seeds or vegetative parts. Regeneration here means the formation and development of new individuals.

There are two main methods of plant propagation: sexual propagation and planting seeds.

Sexual propagation

This method employs the use of seeds. It is important to ensure that seeds selected for propagation are of good quality.

The selection of good quality seeds are guided by the following characteristics:

- **Varietal purity** – They should be free from weed seeds and seeds of other crop varieties. That is they should be genetically true-to-type.
- **Germination percentage** – This is the percentage of the number of seeds in a seed batch that produce normal seedlings. Good quality seeds should have a high germination percentage. A percentage of 85 and above is ideal. Germination percentage helps to determine seed rate.
- **Seed viability** – The ability of seeds to germinate into normal seedlings under optimum soil conditions. It also includes the promptness of germination and the vigour of seedlings.
- **Diseases and pests** – Good quality seeds should be free from seed-borne diseases and pest damages as these tend to reduce seed viability.
- **Visual trait** – Good quality seeds should not be mouldy, shrunken or cracked.
- **Size and shape** – Such seeds should have uniform sizes and shapes.

To obtain good quality seeds for sowing, farmers may grow their own seeds using laid down procedures. They may also buy certified seeds from seed production agencies.

Before sowing, seeds should be chemically treated to protect them and their seedlings from disease infection and pest infestation.

Seed planting

Seeds are either planted (put in the soil and covered to grow) or sown (scattered on the soil to grow as in seed

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broadcasting). The variations in the shapes and sizes of the seeds of different crops determine whether they will be planted or sown.

In planting seeds, holes are made, seeds put into them and the holes covered and firmed. In sowing, seeds are scattered on the soil and covered with a thin layer of soil to protect them from the direct heat of the sun. It also protects them from being picked or damaged by pests or from being washed away by run-off water. Generally small seeds like those of tobacco, rice and millet and most vegetable seeds are sown whilst large seeds like those of cowpea, maize and groundnut are planted. Again most small seeds are grown better by first sowing them at a nursery to produce seedlings which are later transplanted onto a prepared field. Large seeds are commonly planted directly in the field. That is, they are planted **at stake** or **in situ.**

Seeds are planted or sown using the following methods:

- **Broadcasting** – This method of seed sowing involves the uniform and random scattering of seeds onto a seedbed or the field. On the field, seed may be broadcast manually or mechanically using seed broadcasters.
- **Drilling** – In drilling, seeds are planted in a continuous band of tiny furrows in rows and then covered. It is done manually or by using seed planters. In this method inter-row distances are fixed and can be determined but there are no intra-row distances.
- **Precision planting** – This involves planting seeds (normally 2 to 3) at specific distances between plants and between rows of plants, e.g. if a crop has a recommended planting distance of 60 × 40 cm, it means planting holes are 60 cm apart and their rows are 40 cm apart.
- **Random planting** – This method of seed planting employs neither special planting distances nor planting patterns. The method is commonly used in mixed cropping.

Successful planting of seeds depends among other factors on the time of planting, depth of planting and plant population.

Time of planting

Factors that influence the selection of planting time are rainfall, temperature, day length and maturity period of crops; others are incidence of diseases and pests and the availability of labour and market. Generally, however, crops are planted at the beginning of the rainfall season when there will be adequate moisture and temperature for seed germination and for the growth and development of the crops before the rainy season is over. Crops such as maize, cowpea or millet may also be planted at a chosen time within the ideal cropping season in order for them to mature immediately after the rains. This is to provide suitable weather conditions for harvesting and processing the produce.

Planting depth

The recommended depths for planting seeds are dictated by seed size, soil moisture status and soil texture. Large seeds are generally planted at depths greater than the depths to which smaller seeds are planted. This is because large seeds tend to have enough stored food to carry them through the germination and seedling emergence processes. Also under dry conditions when limited soil moisture is available only deep down the soil, seeds are planted deeper for them to encounter moisture for germination. It is also known that seedlings tend to emerge more easily from greater depth in sandy soils than in clayey soils explaining the role of soil texture in the determination of planting depth.

Plant population and spacing

Plant population is the number of plants per hectare of farmland. Generally crop yields increase with the increase in plant population up to the point where competition for soil water, nutrients and sunlight becomes intense. Very high plant population will therefore reduce crop yields while excessively low plant population also cuts down yields as a result of unused land spaces and the resources contained therein. There is therefore the need to determine optimum plant population to sustain profitable crop yields. This can be achieved by determining and using appropriate plant spacing in terms of both intra-row and inter-row distances for crops planted in rows. Plant spacing varies from plant to plant since it is dependent, among other factors, on the growth habits of plants. Growth habit is the relative spread of plant canopy and root system.

Plant population (PP) is given by the product of the number of crop stands per hectare of land and the number of plants per stand.

The number of stands is also calculated by dividing 10 000 m^2 (one hectare of land) by the feeding area (FA) of a plant or stand of plants in square metres.

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That is, number of stands $= \frac{10\,000\ m^2}{FA(m^2)}$

Therefore, $PP = \frac{10\,000\ m^2}{FA(m^2)} \times$ No. of plants per stand

It is worth noting that where the area of the farmland is more or less than a hectare, the area of the farm is determined in square metres and used in the formula in place of one hectare.

Worked example

A farmer plants two maize seeds per hole at a spacing of 30 cm by 90 cm on a hectare of farmland. Calculate the plant population if there was 100% germination.

Solution

$$\text{No. of crop stands} = \frac{\text{Area of farm } (m^2)}{\text{Feeding area per stand } (m^2)}$$

$$= \frac{1 \text{ hectare}}{0.3 \times 0.9\ m^2}$$

$$= \frac{10\,000\ m^2}{0.27\ m^2}$$

$$= 37\,037 \text{ stands}$$

$$\text{Plant population} = \text{No. of stands} \times \text{No. of plants per stand}$$

$$= 37\,037 \times 2$$

$$= 74\,074 \text{ plants}$$

The objectives of successful planting are therefore to attain:

- adequate plant population
- desired plant spacing both within their rows and between rows
- proper planting depth
- timeline of planting.

Nursery and nursery practices

A plant nursery is a carefully selected site where seedlings are raised on seedbeds or in containers such as seed boxes, trays, plastic bags or baskets. Nursery beds should be free from disease pathogens, pests and weeds. They should also be free draining and rich in nutrients to ensure successful seed germination and seedling establishment. A nursery is better sited in open places with free flow of air and adequate sunlight. It should be close to a reliable source of clean water to enhance regular watering of the seedlings.

Seeds are sown in nurseries by **drilling** or **broadcasting** them. Sown seeds should be covered with a thin layer of soil and mulched with grass or other suitable mulching materials. Beds are then watered regularly until germination occurs. Soon after germination, the mulches are removed and light shade raised some 30 cm above the seedbed. The shade protects the delicate seedlings from the intense heat of sunlight and the impact of heavy raindrops. Besides shading, pricking-out and hardening-off are other important nursery practices worth discussing.

Pricking-out

At their first tree leaves stages, that is, about 5 to 7 days after germination, seedlings are transferred onto fairly larger nursery beds or seed boxes at a spacing of about 4 cm. This process is known as **pricking out**. Pricked out seedlings are watered and shaded for 3 to 4 days to enable them to establish.

Pricking out is a tedious and expensive exercise but it has many advantages including the following:

- It helps eliminate late germinators since only vigorous seedlings are pricked out.
- It reduces competition by seedlings for nutrients, soil moisture and sunlight.
- There is no overcrowding of seedlings resulting in reduced incidence of diseases.
- It gives farmers a good count of the number of viable seedlings.
- It enables farmers to get seedlings of uniform size for transplanting.

Hardening-off

Normally, nursery conditions and practices are designed to ensure the growth of delicate seedlings. It is therefore necessary to prepare seedlings to meet and survive harsher field conditions when they are transplanted. This preparatory process of seedling is what is referred to as **hardening-off**.

Hardening-off is done when seedlings are 2 to 3 weeks old. It involves the gradual exposure of seedlings to higher light intensity and temperature and to increasing periods of reduced water supply. This may be accomplished by gradually reducing the shade over the seedlings. If prick out boxes are used, the boxes containing the seedlings are carried from time to time from the shady part of the nursery, left in the sun and rain and later returned to the nursery.

Hardening-off helps the seedlings to accumulate carbohydrates in their tissues for use in quickly producing roots after transplanting. It also helps transplants to

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withstand dry winds, intense sunlight and temperature variations.

Transplanting

Transplanting is the physical transfer of seedlings from the nursery for planting in the field when they are five weeks old. It is advisable to transplant seedlings at the time of the day when light intensity is low and therefore the rate of transpiration is also low. This is to enable the transplants to recover and establish rapidly. Early mornings, late afternoons and cloudy days when humidity is high are the best times to transplant seedlings.

Generally seedlings should be watered before they are removed for transplanting. This is to soften the soil around the roots of the seedlings to significantly reduce or avoid root damage during their removal. However, seedlings transplanted in the mornings of clear days should be immediately heavily watered so that the high afternoon temperatures do not affect their establishment. They should also be watered and NPK fertiliser, in a liquid form, applied lightly.

Vegetative propagation

Vegetation propagation, also referred to as **asexual reproduction** is the use of non-reproductive parts of plants to induce the formation of roots leading to the development or re-generation of plants.

Vegetation propagation may be described as **natural** or **artificial** depending on the extent of human interference in and regulation of the process of propagation.

- **Natural vegetative propagation** – This involves the use of naturally modified vegetative structures such as bulbs, corms, stem tubers, rhizomes, runners and off-shoots. Off-shoots include suckers, slips and crowns. These structures produce new plants and renew themselves in the process because they are naturally endowed with food reserves to enable them to survive adverse environmental conditions. They also provide plants with means of spreading.
- **Artificial vegetative propagation** – in this method humans interfere by inducing and regulating the growth of new plants from prepare vegetative structures. **Cuttage, layering, budding** and **grafting** are the most commonly practised artificial vegetative propagation methods. Cuttage is the use of root, stem or leaf cuttings to propagate crop or plants.
- **Tissue culture** – Tissue culture is a special artificial vegetative propagation method of crops involving the use of minute plant parts in an artificial medium under aseptic conditions. A common example of the use of this method is the use of minisetts in yam cultivation. The numerous advantages of tissue culture include the following:
  - rapid propagation of plants
  - economic use of planting materials
  - production of disease-free plants
  - better production programming
  - high quality produce.

Post-planting activities (cultural practices)

Cultural practices are crop management practices carried out on crop farms after crops have been planted and before they are harvested. They include thinning-out, pruning, staking, manuring, weed control, watering (irrigation), shading, mulching and the control of pests and diseases. A discussion of some of these practices follows:

Thinning-out

Ideally a stand of plants consists of a maximum of two plants but during seed planting at stake, two or more seeds are planted per hole to forestall the likelihood of some seeds not germinating. Where more than the recommended number of seedlings emerges per stand, the extra seedlings are removed in a process called **thinning-out.**

Thinning-out is important because

- it reduces competition among seedlings and ensure normal growth
- it checks disease incidence among seedlings and mature crops
- in crops such as onions and carrots it prevents misshaping of produce.

During thinning-out, weak/diseased seedlings should be removed and the healthy and strong ones left to continue their growth. It is a good agronomic practice to water seedlings before thinning-out. This is to ensure that the roots of the seedlings not thinned out are not damaged.

Supplying (filling-in)

Filling-in is the replanting of seeds at specific spots where planted seeds have failed to germinate or died soon after germination. It is undertaken when planting is done at stake involving crops such as cowpea, maize and some vegetable crops, e.g. okro.

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Filling-in should be done before two weeks of first planting. This is to avoid variations in seedling size and the shading of younger seedlings by older ones resulting in poor growth and low yields.

Weed control

Weeds are to be controlled primarily to avoid competition between growing crops and weeds for soil nutrients, moisture and sunlight. This will ensure optimum growth, development and yield of crops. It also checks pests and diseases attacks and keeps the farm clean.

Weeds may be controlled **mechanically** (using cutlasses, hoes, cultivations, etc.), **culturally** (mulching, crop rotation, flooding, burning, etc.), **chemically** (using weedicides or herbicides), or **biologically** (using living organisms as in cover cropping).

Watering (irrigation)

Water is crucial in the establishment, growth and development of crops. This is because watering or irrigation is done to:

- supply adequate moisture to plants
- provide a suitable medium for soil nutrients to dissolve in for absorption by plant roots
- regulate soil temperature
- maintain plant turgidity to avoid wilting and lodging of plants
- cool the temperature of the plant body through transpiration.

In large scale farming water is artificially supplied to growing crops through irrigation. Methods of irrigation in common cases include furrow irrigation, sprinkler irrigation, and drip (trickle) irrigation.

Mulching

Mulching is the use of suitable materials to cover the surface of the soil in a layer of about 6 cm in thickness. Suitable mulching materials (mulches) include dry grass, sawdust, corncobs, paper and rice straw. Mulching soils helps to

- conserve soil moisture especially in the dry season
- suppress weeds
- check soil erosion
- improve soil organic matter content through decay of organic mulches
- increase water infiltration into the soil
- regulate soil temperature.

Fertiliser application

Fertilisers are applied on farms to supplement the nutrient contents of soil. This, in turn, helps to meet the nutrient requirements of crop plants for growth and development. (See page 207)

Staking

Staking is the process of providing physical support for plants to grow on. Materials used in staking are usually in the form of wooden poles. It is important to ensure that staking materials

- are free from thorns
- can last for about 3 years
- are strong enough to be able to support the plant and not the other way round
- do not interfere with the growth of the root systems of the staked plants
- are not too fresh and green to sprout quickly.

Staking is done to achieve the following objectives:

- to help climbing plants and other plants to sufficiently display their leaves to receive enough sunlight for photosynthesis
- to reduce the incidence of pests and diseases as there is good aeration and low relative humidity
- to facilitate weeding on the farm
- to reduce rotting of fruit vegetables
- to produce clean and attractive fruits
- to encourage early and uniform ripening of fruits
- to make harvesting of produce easier and faster.

Pruning

Pruning is the removal of parts of plants to achieve some agronomic or horticultural objectives. Any part of a plant, the root, branches, leaves or buds, may be pruned depending on the growth habits of the plant and the purpose of pruning. Pruning may be done using a cutlass, pruning shears, pruning saw, a pair of secateurs or pruning knife.

Some of the objectives of pruning are to

- remove diseased or damaged plant parts
- improve aeration within the plant
- improve the penetration of sunlight onto the plant
- give plants desired shapes and forms
- promote fruit formation
- enhance uniform ripening of fruits
- control the size of plants

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- facilitate the performance of other cultural practices through space creation.

Pests and disease control

In crop production, pest and disease attacks reduce the quality and market value of crops, reduce yields and increase the cost of production. Farmers are therefore to control pests and diseases both in the field and storage if they are to make reasonable profits.

Methods used to control crop pests and diseases are classified as follows:

- physical methods
- chemical methods
- cultural methods
- prohibition
- integrated pest management
- biological methods.

Physical methods

These methods involve the use of devices and means that affect the physical environments of pests and pathogens resulting in their destruction. They include the use of barriers to protect crops against large pests as well as microscopic pathogens that are carried and transmitted by insect vectors. Fencing farms to keep out rodents, screening crops to keep off birds and insects and wire-netting seedlings of crops such as citrus, oil palm and coconut, are also used. Furthermore, heat sterilisation of soils, the use of traps and scarecrows as well as noise making also physically control pests and diseases.

Chemical methods

These methods employ the use of chemicals collectively called pesticides to control various types of pests and disease pathogens (Table 3.8).

Table 3.8 Pests and their pesticides

Pest/Pathogen	Pesticide used
insects	insecticides
rodents	rodenticides
birds	avicides
nematodes	nematicides
fungi	fungicides
bacteria	bactericides

Pesticides in common use are in the form of liquids which are sprayed on farms. The use of pesticides in modern day agricultural practices is gradually being de-emphasised because of the following disadvantages of the method.

- Pests develop resistance to pesticides if they are applied frequently.
- Pesticides kill many untargeted organisms disturbing the ecological balance.
- Wrong formulation and over application of pesticides cause injury to crop plants.
- Residual effects of pesticides on edible plants cause serious health hazards to humans and livestock.
- The use of pesticides cause both air and water pollution.

Cultural methods

These methods involve the use of agronomic practices that helps crops escape attacks by pests and diseases by reducing their incidence significantly. They include the following:

- Eliminating diseased seeds and plants (roguing).
- Removing infected as well as infested plant parts through pruning and grafting.
- Good farm sanitation to eliminate intermediate hosts of pests and pathogens.
- Use of clean and healthy planting materials as in seed dressing.
- Crop rotation to starve pests and pathogens and reduce their population drastically.
- Early planting and harvesting to avoid periods when the population of pests and pathogens are at the damage threshold levels.
- Soil tillage to expose soil borne pests and pathogens for destruction by their predators or the sun.
- Use of resistant varieties of crops.
- Heavy organic manuring to control nematodes.

Biological methods

In these methods some living organisms are used to feed on the pests and pathogens, also living organisms, thus controlling them. Examples include

- planting of African marigold to control nematodes
- use of chickens to control cotton stainers in cotton fields
- use of cats to catch and destroy mice and rats especially when produce are in storage.

Prohibitions

These involve legally restricting crops or their planting materials suspected to be carrying pests and pathogens

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from entering a country or being moved within it. This is largely accomplished through the works of the quarantine services of various countries.

Integrated Pest Management (IPM)

The Integrated Pest Management method combines all environmentally friendly measures in controlling crop pests and diseases. Its main objective is to keep the population of pests, some of which may be disease vectors, below the economically damaging threshold level. Below this level, the damage done to crops is economically insignificant.

To achieve its objective, IPM ensures that:

- pests do not have access to the farm
- pests are physically removed from farms
- the chances of pests multiplying to build their population to the damage threshold is drastically reduced.

IPM is now a preferred pests and disease control method because of the following advantages:

- it increases crop yields.
- it leads to the production of good quality produce
- it has little or no adverse effects on the environment
- it costs less to practise since no chemicals are used
- it conserves beneficial pests and predator maintaining a good ecological balance.

Harvesting and post-harvest activities

Harvesting is the final field operation with crops. It should always be given much attention to avoid crop losses in the field. For example, it is important harvesting is done timely. That is, matured crops should be harvested neither too early nor too late. This helps to escape damaging threshold levels of pests and diseases. It also makes harvesting coincide with suitable weather for produce gathering and processing. Harvesting should also be clean and complete in order to avoid produce contamination and to be able to remove as much produce as possible. Additionally, appropriate methods should be used in harvesting crops to prevent damage to harvested produce. The choice of a harvesting method depends on the type of crop and the scale of cultivation. In small-scale farming harvesting is often done manually using such tools as cutlasses, hoes, and mattocks. Large-scale farming relies mostly on mechanised harvesting.

Equipment and machinery designed for harvesting crops include the manual cassava lifter, cereal crops combine harvester and the groundnut combine harvester. (Figure 3.31)

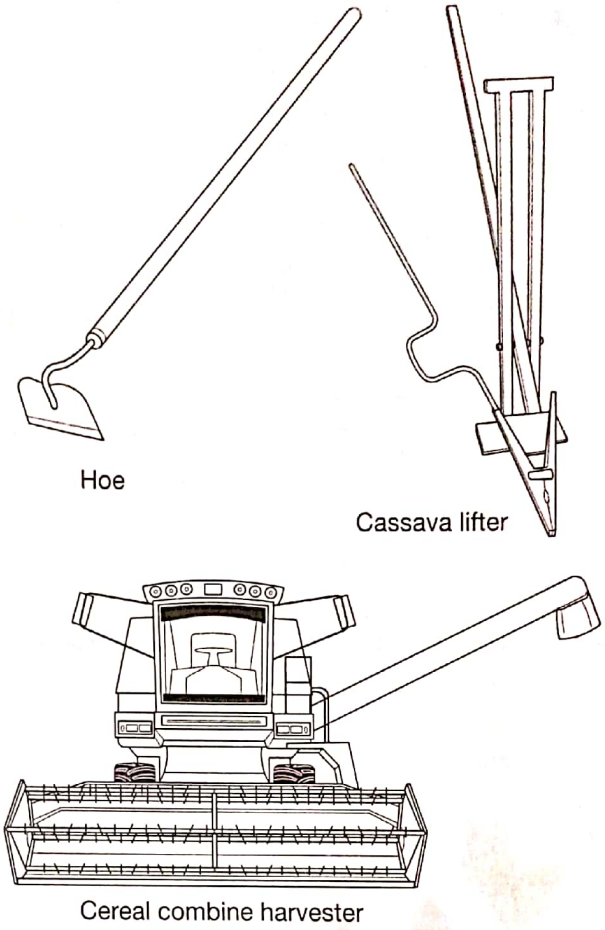


Fig 3.31 Some harvesting tools, equipment and machinery.

Harvesting is often immediately followed by post-harvest activities such as processing and storage.

Processing

Produce processing involves activities that change the natural form and structure of the produce into forms that can be easily utilised, stored or packaged for marketing. Processing methods are unique to specific crops. In the case of cereal crops, for example, the major processing operations are threshing, dehusking, shelling and winnowing. Equipment and machinery are available for these and other processing operations. They include threshing machines, shellers, cassava graters and palm fruit digester. (Figure 3.32)

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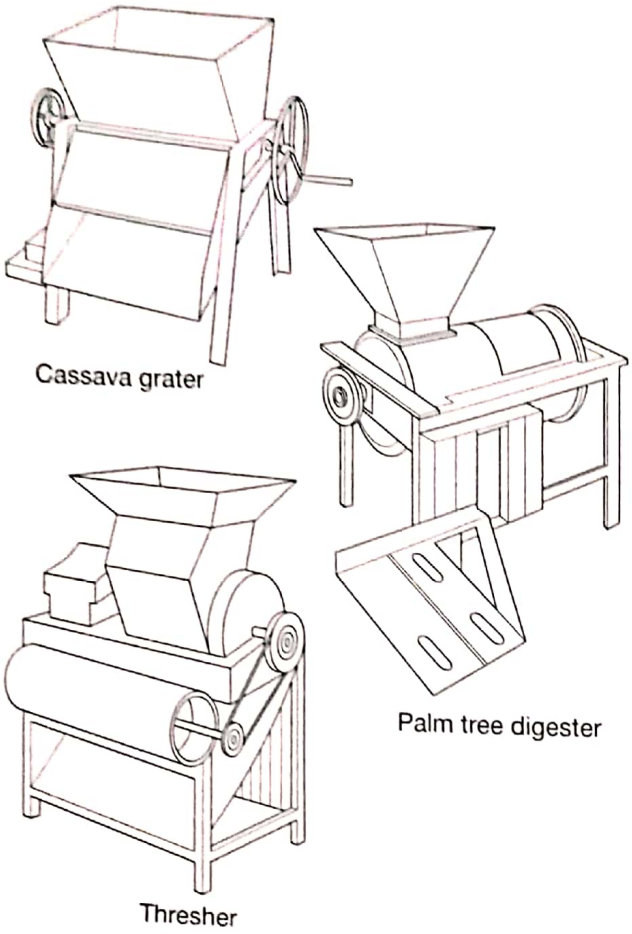


Fig 3.32 Some produce processing equipment and machines.

Storage

This is the holding of a farm's produce in suitable environments and under suitable conditions for a period of time without reduction in the quality of the produce. Farm produce are stored to

- await ripening as in the case of fruits and some vegetables
- ensure their continuous supply and use
- await processing
- take advantage of better market prices in the future.

Refrigerators, bins, cribs and silos are common examples of storage equipment and structures. These structures ensure that storage is effective against all factors of produce spoilage such as storage pests, rain, excessive heat, mould and fungal attack as well as thieves.

Production of crops

Vegetable crops

These are crops that are grown for their succulent parts called vegetables. Vegetables are eaten raw or cooked as part of a diet. Vegetable crops grown in West Africa are grouped based on their origin into local and exotic vegetables. These are further classified based on their edible parts into fruit, flower, leafy, and root vegetables (Figure 3.33).

Vegetables are essential food ingredients for humans because

- they provide vital minerals such as calcium, iron and iodine
- they are valuable resources of vitamins for good health
- they provide carbohydrates for energy
- they neutralise acidic conditions in the human digestive system caused by protein digestion
- they provide roughage which promote digestion and prevent constipation.

Okro (*Hibiscus esculentus/Abelmoschus esculentus*)

Okro, also referred to as Okra, is an annual crop that reaches a height of about 2 metres at maturity. The plant is generally hairy and has alternate three-lobed leaves. The fruit is a capsule which is usually ridged and pointed at the apex. It is generally green in colour but purplish-red coloured fruits are also available. (Figure 3.34)

Common varieties and uses

Two main varieties of the crop are cultivated by small-scale West African farmers: the long finger-like variety and the short rounded-base and blunt-apex variety. Matured okro fruits are harvested fresh and used in preparing soup for a number of West African dishes. The fruits may also be cut into pieces, dried and ground into granular okro substance which can be used to prepare or thicken soups.

Soil and climate

Okro grows in most soils but prefers well-drained soils. It tolerates acidic conditions but it does not do well in heavy clays. The crop requires an annual rainfall of 800 to 1000 mm and an average temperature of about 25°C for optimum growth and development.

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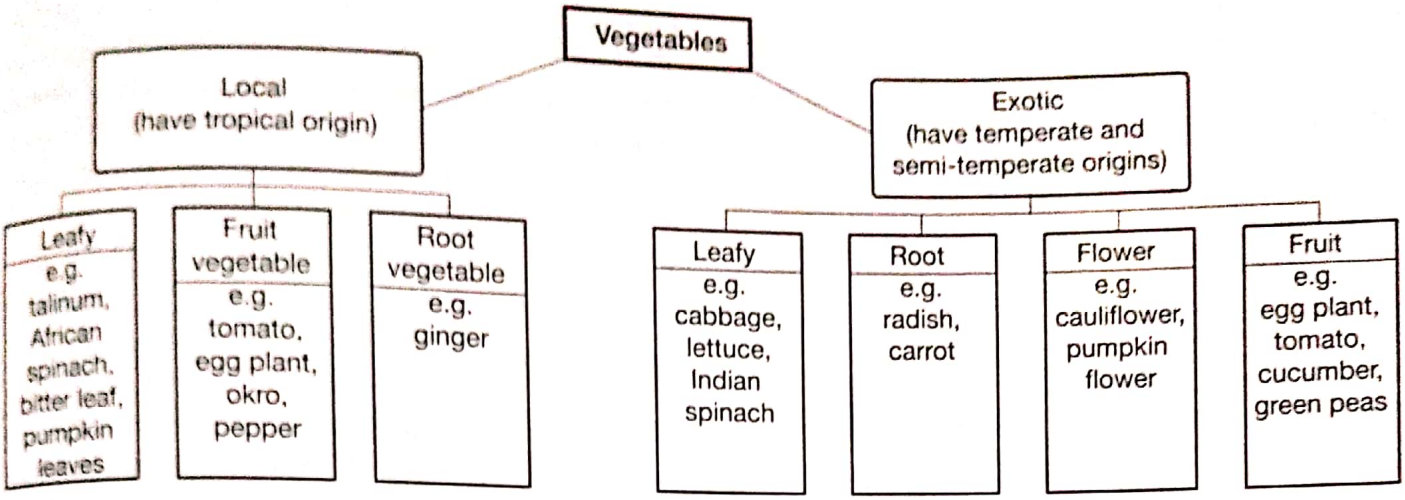


Fig 3.33 Classification of vegetables.



Fig 3.34 Okro plants with fruits.

Planting

Two to three viable seeds are planted at stake on the field or on beds to a depth of 3–4 cm and a spacing of 30–40 cm within rows and 50–70 cm between rows. The crop is planted at the beginning of the rainy season as a sole crop or an interplanted crop. Thinning is done one week after germination leaving one plant per stand.

Cultural practices

If rainfall is inadequate crops should be watered or irrigated up to fruiting stage. A modest incorporation of superphosphate fertiliser into the soil before planting enhances the formation of numerous pods. Top-dressing the crops with a low nitrogen content fertiliser such as NPK, four weeks after planting, stimulates reasonable vegetative growth for efficient photosynthesis.

Pests and disease control

Fruit- and leaf-eating caterpillars such as the cotton leaf caterpillar are the major pests of okro. They eat and kill seedlings, eat leaves and fruits of older plants. These pests are effectively controlled by spraying with Carbaryl or Cypermethrin. Fungal diseases such as powdery mildew and black leaf mould attack both the leaves and fruits of okro. Their control is through clean husbandry, crop rotation and the application of fungicides such as Benomyl and Dinocap. Leaf curl and leaf mosaic are the two important viral diseases of okro. Crop rotation, use of resistant varieties of okro and the use of insecticides to kill the white fly vectors of the leaf mosaic virus effectively control the diseases.

Harvesting

Okro fruits are matured for harvesting 8 to 12 weeks after planting. Fruits are picked by hand or by cutting them with a knife from the plants. Fruits should be harvested regularly on every other day to avoid the toughening and hardening of fruits and to ensure continued fruit formation for a reasonable period of time.

Lettuce (*Lactuca sativa*)

Lettuce is a member of the 'salad crops'. The other members are cabbage and cauliflower. These vegetable crops are known as salad crops because they are largely used in preparing salads. The edible part of lettuce is the leaves. These are eaten fresh and uncooked. Lettuce diets are effective weight-controlling diets as they contain calcium, iron and vitamin A and very few calories or fat.

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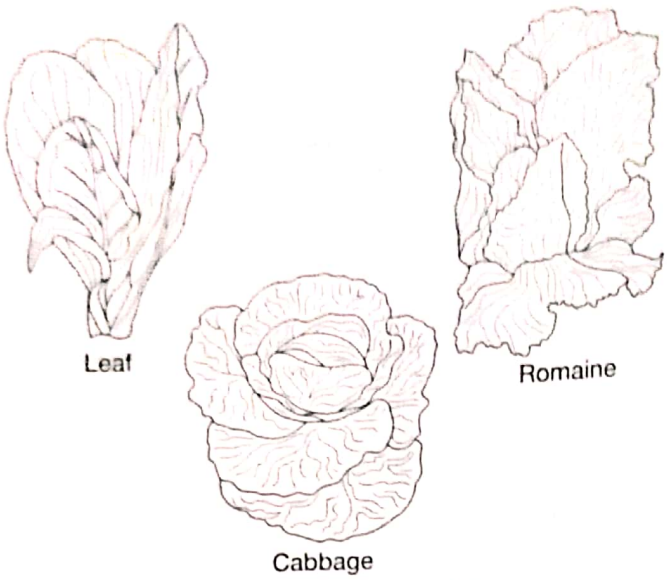


Fig 3.35 Some Lettuce varieties.

Common varieties and types

- **Leaf lettuce** – This variety is non-heading. It rather forms clumps of light green loose or curled leaves. It is the most widely grown variety in West Africa.
- **Cos, or romaine lettuce** – The leaves are coarse-textured and curl inwards. The plant grows long and upright into an oblong structure of curled-in leaves.
- **Cabbage (head) lettuce** – The leaves grow around the centre of the plant forming a ball-shaped head (crisp head) similar to a cabbage head. (Figure 3.35)

Soil and Climate

The crop grows best in sandy loam soils rich in organic matter. A soil pH of about 6.5 and an average temperature of about 18°C are ideal for the crop. As a cool crop it requires a low intensity but well-distributed rainfall.

Sowing

Seeds are thinly drilled in rows that are 25–30 cm apart. After germination seedlings are thinned first to 10 cm apart and later to about 22 cm apart. Seeds may be similarly sown on nursery beds, seedling cared for at the nursery and later transplanted onto the main beds.

Pests and Disease Control

The common pests of lettuce are cabbage loopers, cutworms, aphids and white flies. Their damaging effects on lettuce leaves and stems reduce the quality and market value of the leaves. Steps such as insecticide application and good sanitation should be taken to get rid of these pests.

Downy Mildew

The major foliar diseases of lettuce, which are even more devastating under humid conditions, include **downy mildew**, **bottom rot** and **lettuce drop**. Chemical treatment of soils before planting lettuce and crop rotation prevent these diseases. High relative humidity and too much heat also cause the **Tip burn** disease. Such environmental conditions should therefore be avoided.

Harvesting

Mature lettuce is ready for harvesting 60 to 90 days after sowing, depending on variety. The 'head' forming varieties are mature for harvesting when their heads are firm. Harvesting is done by pulling the heads up and cutting them off at soil level. The leaf lettuce varieties are harvested when their leaves attain the desired density. Harvested lettuce should be kept in cool places prior to eating or sale. This will prevent the wilting of the leaves. The leaves become bitter and less palatable when harvesting is delayed.

Carrot (*Daucus carota*)

Carrots belong to the parsley family of plants. It has a swollen or modified taproot which varies in shape and size. It has a condensed stem from which the fern-like leaves grow and are carried on small branches. (Figure 3.36)

Carrots are grown mainly for their conically shaped roots which are generally orange or pinkish-red in colour. Carrots are eaten raw either alone or in salads. The roots may also be eaten roasted or boiled. They contain iron, vitamin B_1 and small amounts of vitamins

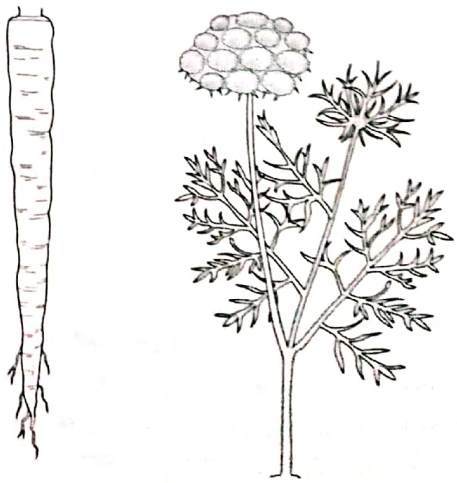


Fig 3.36 Carrot plant showing the root.

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B, and C. They also contain the substance **carotene** which the human body uses to produce vitamin A. Eating carrots therefore promotes healthy living. The leaves and stem are also edible.

Soil and Climate

The crop grows well in sandy or sand loam soils which allow a uniform swelling of the taproot to form the modified root which is the economic part of the crop. The soil should have a pH of about 6.0. Carrot is a temperate crop and therefore thrives best under low temperature conditions, ranging from 15°C to 24°C. Growing the crop under warm conditions produces roots that are fibrous in texture and small in size.

Sowing

Carrot seeds are very small. They are therefore sown directly on beds by drilling the seeds thinly to a depth of 20–22 cm in rows. The rows should be 30–35 cm apart. The sown seeds should be lightly mulched and watered until germination occurs in about 2 weeks. After germination, seedlings are thinned to about 4 cm apart to reduce overcrowding and promote growth and development. A second thinning to about 12 cm apart when crops are 4–5 weeks old is recommended. It is important to remove seedlings when their roots begin to show and to continue moderate watering.

Fertilisation

The fertiliser requirements of the crop are low but a modest application of potassium fertiliser promotes the formation of the roots. The use of organic manures is not advisable as this induces the formation of branched roots.

Pests and Disease control

Nematodes are the major pests of carrots. They stimulate the formation of galls on the roots and disrupt plant water supply. Use of resistant varieties of carrots and crop rotation keep these pests in check.

The main disease is **bacterial soft rot** which causes rapid rotting of roots particularly in storage. Good farm sanitation and crop rotation are the most reliable prevention and control measures of the disease.

Harvesting

Carrots are ready for harvesting 70–80 days after sowing. Harvesting is done by pulling out the roots from the soil after the crops have been watered. They are stored in a moist, cool place and washed only when needed.

ACTIVITY 1 Cultivating selected vegetable crops

1 *Work in groups.* Your teacher should divide the class into convenient groups and assign each group to the cultivation of one of the following crops from the nursery stage (if necessary) to harvesting and post-harvest handling stages:
   a) vegetable – okro, lettuce or carrots.
   b) cereal – maize or millet.
   c) legume – cowpea or groundnuts.
   d) root crop – cassava or yam.
2 Group should submit reports for discussion in class.

Self check

For questions 1 to 13, choose the letter that refers to the correct option.

1 Maize is classified as a cereal because
   A it produces seeds **B** it has marrow leaves
   C it has long roots **D** it grows in marginal soils

2 The root nodules of legumes contains
   A nitrogen-fixing bacteria
   B fungi
   C oil
   D nematodes

3 Which of the following activities is carried out in a crop nursery?
   A mulching **B** staking
   C pricking out **D** transplanting

4 Which of the following methods of plant propagation are used for corms?
   A sexual propagation
   B natural vegetative propagation
   C artificial vegetative propagation
   D tissue culture

5 'Filling-in' is practised when crops are planted
   A in the nursery
   B at stake
   C using vegetative methods
   D on slopes

6 Avicides are pesticides used in controlling
   A nematodes **B** rodents
   C insects **D** birds

7 Which of the following methods of pests and disease control is most ecologically friendly?
   A cultural methods
   B physical method
   C integrated pest management
   D biological method

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8 An example of local leafy vegetable is
A African spinach B egg plant
C lettuce D carrot

9 *Abelmoschus esculentus* is the botanical name for
A onion B pepper
C lettuce D okro

10 Which of the following diseases affect lettuce?
A leaf curl B leaf mosaic
C bottom rot D blossom-end rot

11 Mulching is done mainly to
A conserve soil moisture
B conserve soil nutrients
C protect soil microbes
D control leaching

12 Groundnut rosette disease is caused by
A bacterium B fungus
C virus D nematode

13 Classification of crops into annuals, biennials and perennials is based on
A method of cultivation B uses
C botany D life cycle

14 a) What are vegetables? State the nutritional values of vegetables
b) Give an outline of the classification of vegetables using their edible parts as a basis.

15 Discuss the cultivation of maize under the following headings:
a) Soil and climatic requirements
b) Planting
c) Cultural practices
d) Storage

16 a) Distinguish between the following:
(i) budding and grafting
(ii) sexual propagation and vegetative propagation
b) State four benefits of each of the following cropping practices:
(i) staking
(ii) pruning

17 a) Why are legumes important in crop rotation?
b) Name three legumes grown in West Africa.
c) List the major pests and diseases of
i) groundnuts
ii) cowpea
iii) cassava

18 a) What is a crop variety?
b) Discuss five factors that influence the choice of a crop variety for cultivation.
c) State the objectives of successful planting of corps.

19 a) Define the term soil tillage.
b) State five objectives of soil tillage.
c) Why is it important to shade seedlings in a crop nursery?

20 a) What steps should be taken to ensure successful harvesting of crops.
b) Give three reasons why farm produce are processed.

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1 Nervous system

Learning objectives

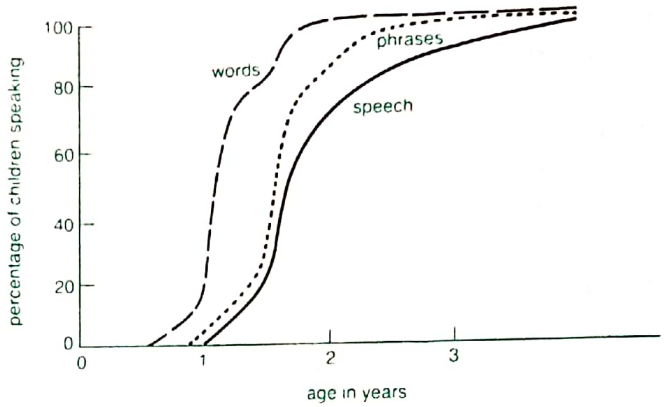
After studying this unit, you should be able to:

1 describe the structure and functions of the nervous system of humans
2 understand the causes and effects of damage to the brain and spinal cord
3 distinguish between voluntary and involuntary actions
4 describe the endocrine system and its functions.

Background information

As humans grow and develop, they not only increase in size but also in their ability to coordinate, such as in manipulation, standing, walking, running and speaking. Figure 3.37 illustrates this, using speech as an example. The body's systems are made to work efficiently together by the **nervous system** and the **endocrine system**.

A appearance of words, phrases and speech



B number of words understood



Fig 3.37 Speech development in humans.

The structure and functions of the nervous system

Central nervous system (CNS)

The CNS consists of the **brain** and the **spinal cord**. Ten pairs of nerves come from the brain (cranial nerves) and 31 pairs from the spinal cord (spinal nerves). These nerves make up the **peripheral nervous system** (Figure 3.38).

The brain

The brain is made up of millions of **neurones** (nerve cells) and consists of:

- **Cerebrum** (forebrain) – the largest part of the brain; made up of two **cerebral hemispheres**. The outer part is a thin layer of **grey matter** and the inner is a thick layer of **white matter.** (Compare with the spinal cord where the grey matter is on the inside.) The outer layer is the **cerebral cortex** and is concerned with such activities as vision, touch, taste, memory and emotion.

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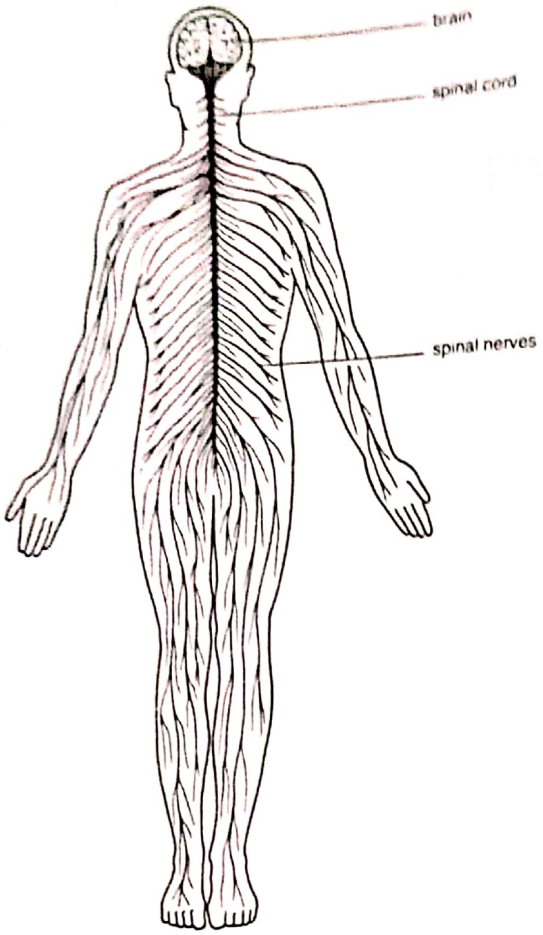


Fig 3.38 Diagram of the nervous system of humans.

It has been possible to chart these areas (Figure 3.39). There are sensory, motor and association areas where information may be remembered and used to make decisions later.

- **Cerebellum** – very important in muscle coordination and balance; used in maintaining muscle tone in posture. It also coordinates muscles during running, walking, riding a bicycle and driving a car.
- **Medulla oblongata** – this region controls many life activities that one does not think about, such as breathing and rate of heart beat.

The cerebellum and the medulla together form the **hindbrain**. Figure 3.40 shows the main regions of the human brain.

Surrounding the brain and protecting it are hair, the cranium (bone) and the meninges – membranes in between which are spaces filled with **cerebrospinal fluid**. This acts as a cushion and provides the cells with food and oxygen (Figure 3.41).

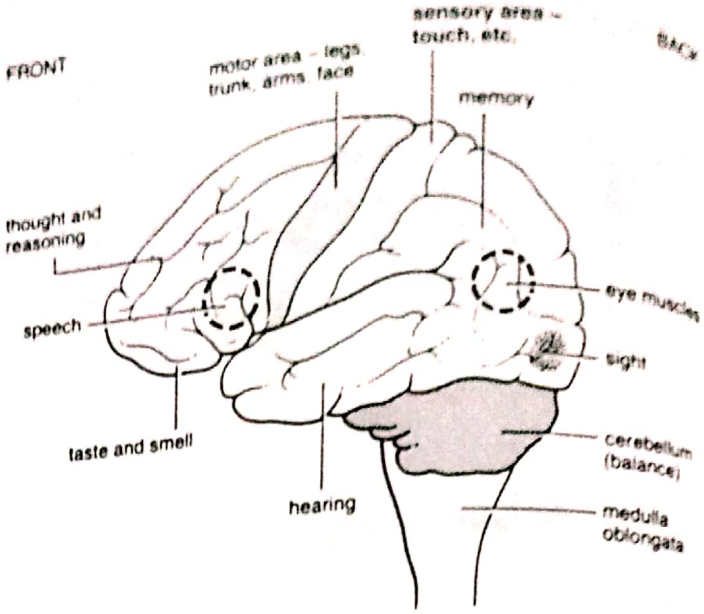


Fig 3.39 Map of half the cerebrum showing various functions.

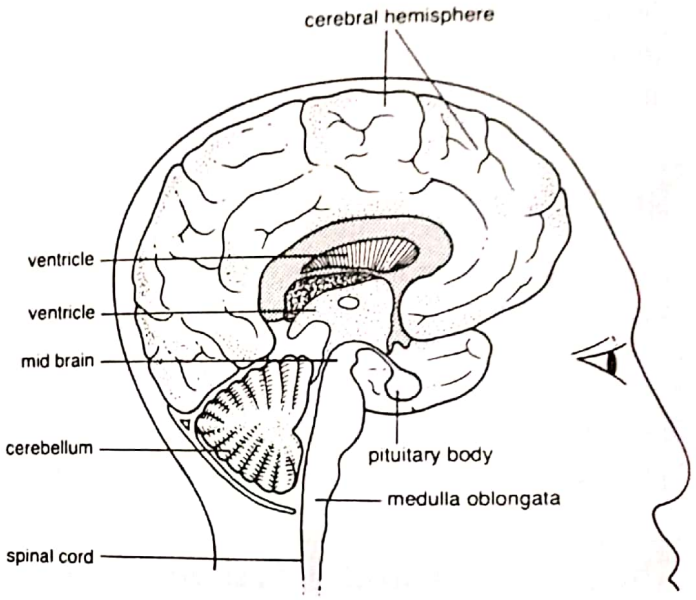


Fig 3.40 Main regions of human brain – side view.

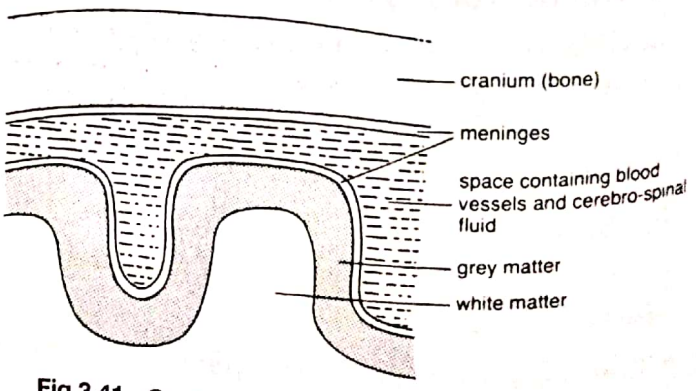


Fig 3.41 Section through skull, meninges and brain.

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Damage to the brain and spinal cord

Many accidents – on the roads, in the air, in homes, at the workplace, etc. – may cause damage to the brain and spinal cord. The damage is usually permanent and irreversible. This is because damaged nerve cells never heal. If part of the brain is damaged, life activities controlled by that part of the brain become impaired and any abnormal behaviour as a result is often permanent and irreversible. Sometimes, however, other parts of the brain can take over some of the life activities so there is a partial recovery.

Organic illnesses such as brain tumours, infections such as meningitis, and biochemical changes in the brain cells can cause impaired body function and changes from normal behaviour.

Damage to the brain and spinal cord has an effect on the individual, family and society. It may result in abnormal behaviour of the affected person who may be unable to:

- tolerate behaviour patterns in other people that are different from his or her own
- form and sustain relationships with other people
- look after his or her own welfare, including personal hygiene and feeding
- make rational decisions and plan for the future
- adjust to stress resulting from changes in the environment, whether physical, such as changes in climate; or social, such as changes in attitudes and behaviour in other people.

Depression

This is a mental disorder in which the patient feels extremely unhappy and has no enthusiasm for anything. It is one of the most common mental illnesses. It may have an internal origin (endogenous) or be a response to the environment (reactive). It is thought that endogenous depression is caused by changes in the way in which the brain cells work, e.g. change in the balance of chemicals produced at the synapses of nerve cells. Reactive depression may be caused by stress such as the death of a loved one, a deep disappointment or frustration, being an exaggerated reaction to the situation which causes it. Extreme tiredness and an inability to take any action can be a feature of depression.

Drug and alcohol abuse

Abusing a drug means its improper use. Some people use drugs such as Indian hemp, cocaine or heroin to help them escape from the unpleasant realities of life. But escape does not remove the cause of the problem. These drugs are called **psychotropic drugs**. They alter a person's state of mind and, particularly, their perception of the world and people around them. For example, the drug LSD may affect the brain cells and distort perception, causing **hallucinations**. The same drug may affect that person's judgement in dangerous situations so that he or she may ignore traffic dangers or jump from a high window believing that they can fly.

Alcohol is a powerful drug that adversely affects the working of the human brain. If it is taken in small quantities it makes people socially more relaxed. However, drinking a lot of alcohol makes people less aware of the world around them. They are more likely to commit crimes, such as stealing, assaulting people or other anti-social acts. Some people feel that taking alcohol helps them to get through the day when they are frustrated or depressed.

Alcohol makes people less able to solve their problems because they do not feel the effect of the problem so acutely when they are under the influence of alcohol. A person who regularly depends on alcohol to get through the day is described as an **alcoholic**. This person has an emotional illness and for this reason alcoholics are often treated in **psychiatric hospitals**.

Drug dependence

Dependence on drugs may be psychological or physiological. **Psychological dependence** means that the person has become used to taking the drug and feels that he or she really needs it and must have it. People may become psychologically dependent on alcohol, tobacco, coffee, cocaine, heroin and other **addictive drugs**. When a drug is used for a long period of time, the body becomes used to it and develops tolerance. This is a **physiological reaction** and means that the body can cope with increasing quantities of the drug. It also means that the person has to take increasing amounts of the drug in order to achieve the desired effect. **Physiological dependence** on a drug is termed **addiction**. In this case the drug has brought about changes in the way one or more organs function. The person becomes very ill without the drug and suffers from **withdrawal symptoms**. An alcoholic may suffer from **delirium tremens** (frightening hallucinations, tremors and over-activity of internal body organs) if alcohol is not taken.

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Voluntary and involuntary actions

Voluntary actions involve the conscious part of the brain. Previous experience is involved and a choice is made, so one makes a conscious decision to sing, talk, run or write, etc. Involuntary actions are reflex actions not under the control of the will. They are automatic and quick. Table 3.9 compares the two kinds of action.

Table 3.9 Comparison of voluntary and involuntary actions

Spinal reflex	Voluntary action
• stimulus affects external, or internal receptors	• initiated from the brain at the conscious level
• spinal cord only involved – not under conscious control	• forebrain involved – under conscious control
• the impulse travels only up or down the spinal cord	• the impulse travels from the brain down the spinal cord
• the path of the nerve impulse is by the shortest route	• the path of the nerve impulse is much longer
• the response is immediate	• the response can be delayed
• the response is in skeletal or an internal involuntary muscle	• the response is in skeletal muscle only

Many of these actions are controlled by the **autonomic nervous system**, which is made up of two types of nerve – **sympathetic nerves** and **parasympathetic nerves**. Table 3.10 shows some of the activities which these nerves control.

Table 3.10 Summary of activities controlled by the autonomic nervous system

Parasympathetic system	Sympathetic system
• slows heart	• speeds up heart
• dilates arteries	• constricts arteries
• constricts pupils	• dilates pupils
• increases saliva flow	• decreases saliva flow
• speeds up peristalsis	• slows down peristalsis

Reflex actions

A reflex action is behaviour in which a stimulus produces an immediate and automatic response. For instance, if you touch something hot, you pull your hand away very quickly; if a bright light is shone into your eyes, the pupils contract. Reflex actions are important because they enable us to escape quickly from danger, before consciously knowing we are in danger. This ability goes a long way to protect the life of the organism. Figure 3.42 shows

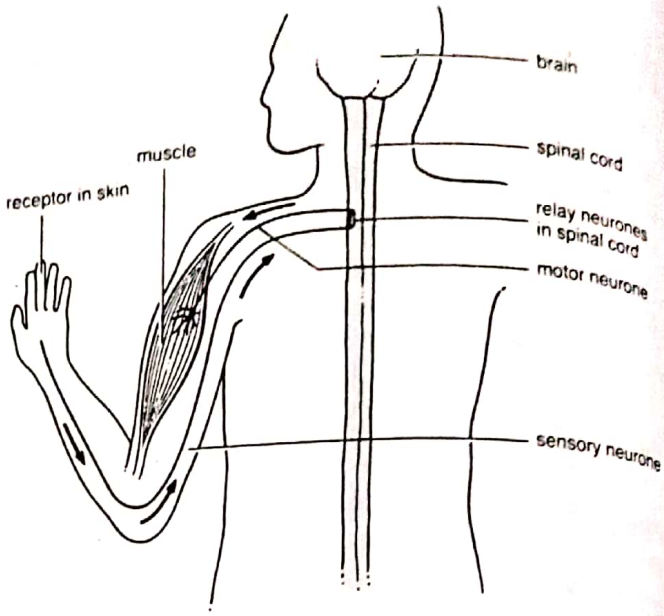


Fig 3.42 Generalised reflex arc.

a generalised reflex arc and the three types of neurones involved – **sensory**, **relay** and **motor** neurones. Figure 3.43 shows a nerve and a motor neurone in detail. Note that a nerve is made up of a large number of neurones.

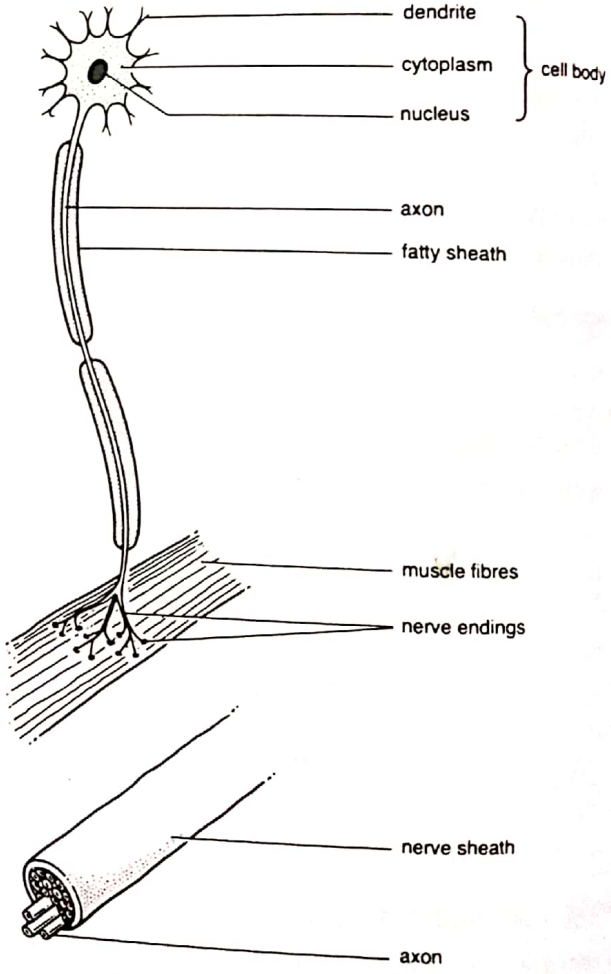


Fig 3.43 Motor neurone and nerve.

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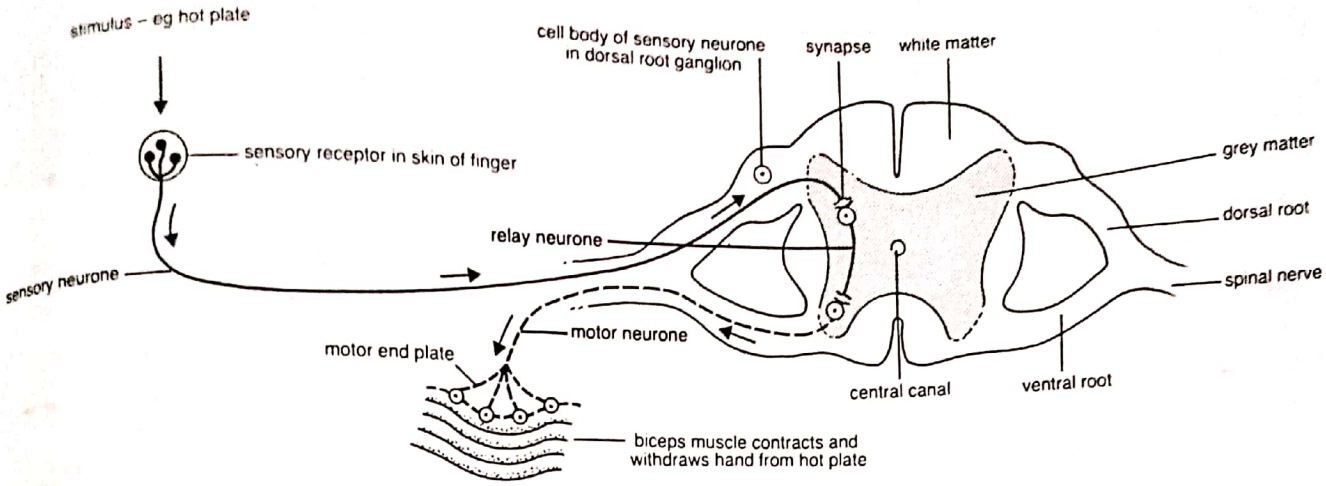


Fig 3.44 Analysis of a reflex action.

How reflex actions work

If a hot plate is picked up, heat receptors in the skin are stimulated. An electrical impulse passes along a **sensory neurone** which enters the spinal cord via the dorsal root. The impulse now moves over a synapse (gap) and stimulates a **relay neurone**. The same happens at the end of this neurone and a **motor neurone** is now stimulated. The impulse travels out of the spinal cord via the ventral root to the muscles and they contract and pull the hand away (Figure 3.44).

It is thought that the impulse travels down a neurone due to a change in the electrical charge on the inside and outside of the nerve cell (axon). How the impulse passes over the synapse can be seen in Figure 3.45.

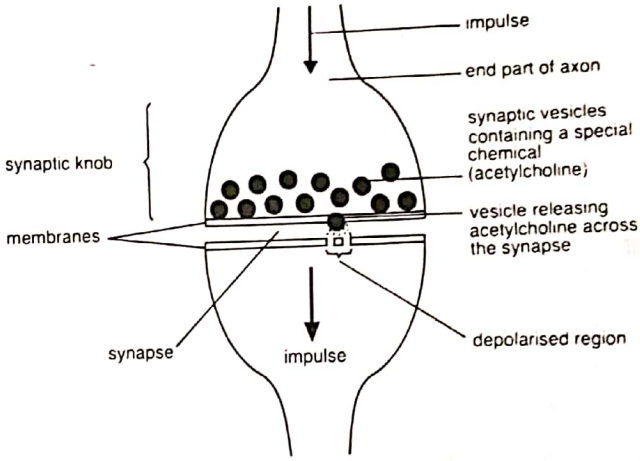


Fig 3.45 How an impulse travels across a synapse.

ACTIVITY 1 Demonstrating a spinal reflex

1 Sit on a stool with your right leg crossed over the left knee. Tap the patella tendon (just below the kneecap) of your right knee sharply with the edge of your hand. What happens?

2 Now place your left hand on top of your right thigh muscle. Repeat the tapping of the patella tendon. What do you feel with your left hand?

3 What explanation can you give for the response of your lower leg?

The tap on the tendon causes the stretch receptors of the thigh muscle to be stimulated and the muscle contracts. This muscle is an extensor muscle of the knee joint, and the lower part of the limb jerks forward. Thus we have a simple behavioural pattern called a reflex action. It results from a sequence of impulses in the nerves and the spinal cord constituting a reflex arc. The reflex arc sequence is as follows:

- the tap on the tendon stimulates the receptors in the muscle
- the receptors generate an impulse which is transmitted along the sensory neurone to the spinal cord, where it is passed via a relay neurone to an outgoing motor neurone
- the impulse proceeds along the axon of the motor neurone and causes the extensor muscle in the top of the thigh to contract.

The knee jerk reflex is a spinal reflex action involving only the spinal cord, and, like all reflexes, it is not under a person's control. It is not initiated consciously and it

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cannot be suppressed. Nevertheless, when it happens, we are conscious of it because a further impulse is sent along the spinal cord to inform the brain. We are then made aware of the response.

One astonishing feature of reflexes is that they are very quick. For example, if you accidentally stepped on something sharp, your responses would occur as follows:

- **zero ms** (milliseconds) – a splinter penetrates the foot. A message is flashed to the base of the spine.
- **60 ms** – the message is received by a nerve junction in the spinal cord. A message is sent to the brain. Orders are immediately sent to the leg muscles.
- **69 ms** – orders reach the leg muscles. The damaged foot is lifted, while the weight of the body is transferred to the other foot.
- **100 ms** – a damage report has reached the brain. A signal is sent to the vocal cords.
- **115 ms** – suitable words are chosen and may be spoken out loud, but it is some time before the brain is fully conscious of what has happened to the foot.

ACTIVITY 2 What happens when we cut up an onion?

1 Take an onion and cut it into small pieces.

2 Describe what happens to the nose and eyes.

The vapours arising from the cut onion pass into the nose and eyes causing the olfactory sense cells to react. In addition, the vapour dissolves in the moisture of the eyes. The eyes react by discharging fluid from the tear glands to dilute the dissolved vapour. Here is a clear reflex action, not controllable by the will and giving a definite response to the chemical stimulus. In this case, however, although automatic, the reflex action involves the brain rather than the spinal cord, so it is called a cranial reflex action. The response is a glandular discharge as distinct from the muscular action in the case of the knee jerk.

ACTIVITY 3 Investigating heartbeat

1 *Work in groups* to design an experiment to investigate heartbeat (a) at rest and (b) after strenuous exercise.

2 What do you expect to be the difference between (a) and (b)?

3 Discuss in your group the reasons for this difference.

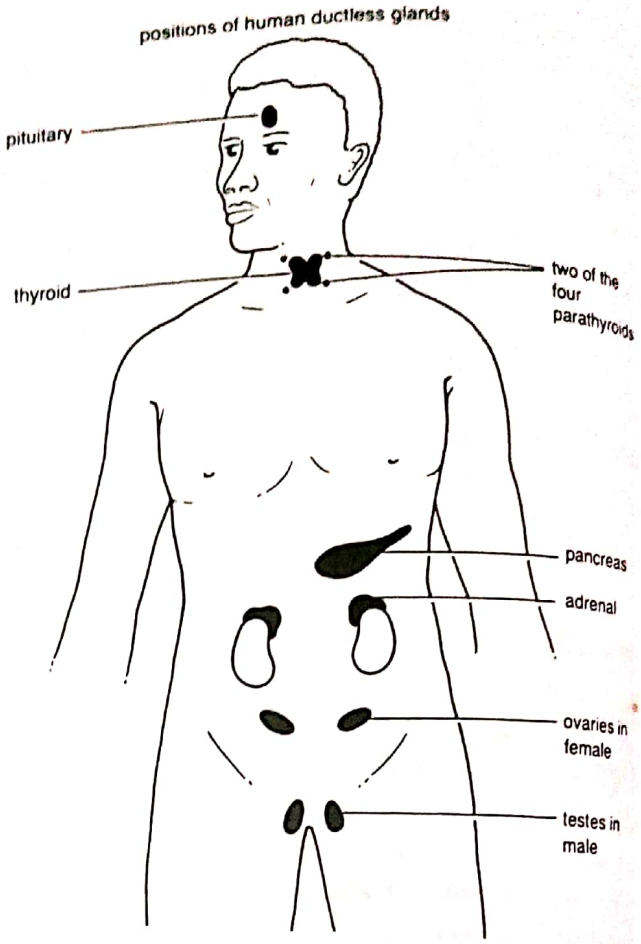


Fig 3.46 The endocrine system.

The endocrine system

Coordination by the nervous system is usually rapid and very precise. A different kind of coordination is brought about by the endocrine system. This system depends on chemicals called **hormones**, which are released from special glands, called **endocrine glands**, into the bloodstream.

There are two types of glands in the mammalian body which produce secretions. Some of them give out their secretions through ducts or tubes. These glands are called **exocrine glands**, for example tear and salivary glands. Others do not have ducts and therefore produce their secretions directly into the bloodstream by means of diffusion. These glands are called **endocrine** or **ductless glands**. The different types constitute the **endocrine system**. The endocrine system comprises of different glands which secrete hormones.

The study of the endocrine system is referred to as **endocrinology.** A gland is a group of cells which secretes fluids that another part of the body uses.

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Table 3.11 The endocrine glands and their functions

Gland	Position in body	Hormone secreted	Response of body to hormone	Effects of under- or over-production
thyroid gland	neck	thyroxine	controls basic metabolism and growth rate	deficiency causes dwarfism and mental retardation in children and myxoedema in adults; over-production causes increased metabolism
islets of Langerhans	pancreas	insulin	controls balance of sugar in blood	under-production of insulin causes deficiency results in diabetes mellitus, diagnosed by the presence of sugar in the urine
		glucagon	released when the blood glucose level is low, causing the liver to convert stored glycogen into glucose and release it into the bloodstream	
adrenal gland (medulla)	attached to the kidneys	adrenaline	controls response for 'fight or flight', i.e. increases heartbeat and blood glucose level, dilates coronary arteries, etc.	
pituitary gland	at the base of the forebrain	growth hormone	stimulates growth	deficiency causes dwarfism, cretinism. Over-production causes gigantism
		thyroid-stimulating hormone (TSH)	stimulates production of thyroxine	
		follicle-stimulating hormone (FSH)	maturation of Graafian follicles in females	
		testis-stimulating hormone	stimulates production of sperms in males	
		leutinising hormone (LH)	stimulates ovulation and development of corpus luteum in females	
		prolactin	stimulates production of milk	
		anti-diuretic hormone (ADH)	stimulates reabsorption of water by the kidney tubules	
		oxytocin	simulates contraction of uterus during birth	
parathyroid gland	at the top of the thyroid gland in the neck	parathormone	stimulates release of calcium from bones into blood	
testes	inside the scrotum	testosterone	development of male secondary sexual characteristics	deficiency results in an inability to develop secondary sexual characteristics
ovaries	just posterior to the kidneys	oestrogen	controls development of female secondary sexual characteristics	deficiency result in an inability to develop secondary sexual characteristics
		progesterone	development of uterine wall ready for implantation	

Hormones are chemical substances produced in one part of the organism by the cells of the endocrine glands and transported to **target organs** to produce physiological effects.

Hormones are unstable and therefore quickly destroyed. Over-secretion of some hormones leads to hyper function and under-secretion leads to hypo function.

The glands that constitute the endocrine system include

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the pituitary, thyroid, parathyroid and adrenal glands as well as the gonads (male and female), pancreas and placenta. The majority of the pituitary hormones, called stimulating hormones, regulate the activities of other glands. The pituitary gland is therefore called 'master gland'. The thyroid gland, the adrenal gland and the gonads are all affected by stimulating hormones from the pituitary gland.

The pancreas can be both exocrine (release of pancreatic juice) and endocrine (release of insulin and glucagon).

Three very important hormones are thyroxine, insulin and adrenaline. Table 3.11 gives information about these. Table 3.12 compares the nervous and endocrine systems.

Table 3.12 Comparison of nervous and endocrine activity

	Nervous control	Endocrine control
stimulus	through external or internal receptors	through external or internal receptors
linking mechanism	central nervous system and nerves	blood and circulatory system
effectors	muscles and glands	whole body, organs or organ systems
speed	rapid reaction – reflex arc or voluntary nerve paths	relatively slow as the hormones travel via the bloodstream
effect	effect of response is short	effect is long
response	Response is localised	Response is often widely distributed

Iodised salt

Iodised salt is table salt mixed with a minute amount of potassium iodide or sodium iodide. Iodised salt is used to help reduce the chance of iodine deficiency in humans. Iodine is important to prevent the insufficient production of thyroid hormones, which can cause problems such as goitre and cretinism in children. It is therefore an important dietary supplement.

Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 The peripheral nervous system of mammals is made up of ten pairs of cranial nerves and
A 42 pairs of spinal nerves
B 35 pairs of spinal nerves
C 31 pairs of spinal nerves
D 21 pairs of spinal nerves

2 The part of the mammalian brain concerned with such life activities as memory, vision, touch and taste is the
A cerebral cortex **B** cerebellum
C optic lobe **D** medulla oblongata

3 Which part of the mammalian brain controls breathing and rate of heartbeat?
A cerebrum **B** medulla oblongata
C cerebellum **D** optic lobe

4 The disorder of the brain in which a person becomes extremely unhappy and has no enthusiasm for anything is known as
A depression **B** phobia
C anxiety **D** psychosis

5 Which of the following hormones controls balance of sugar in the blood of mammals?
A adrenaline **B** insulin
C thyroxine **D** testosterone

6 **a)** Distinguish between voluntary and involuntary actions and give two examples of each.
b) A boy stepped on a thorn and quickly lifted his foot without thinking. Describe the events leading to the lifting of his foot.
c) What is the importance of reflex actions?

7 **a)** Write a brief description of the symptoms of depression.
b) Explain how damage to the brain and spinal cord can affect society.

8 Copy and complete the table below concerning hormones in humans.

Gland	Location in body	Hormone secreted	Function of hormone	Effect of under secretion
thyroid				
islets of Langerhans				

9 Compare the actions of the nervous and endocrine systems of mammals under the following headings:
a) stimulus **c)** effects
b) linking mechanism **d)** speed.

10 **a)** What is drug abuse?
b) Explain how (i) drug abuse and (ii) alcohol abuse can affect the normal functioning of the brain.
c) Explain the psychological and physiological implications of drug dependence.

11 **a)** Where is the pituitary gland situated?
b) Why is it referred to as the 'master gland'?

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1 Light energy

Learning objectives

After studying this unit you should be able to:

1 review reflection and refraction of light and characteristics of images formed by plane mirrors
2 draw and describe the mammalian eye, functions and eye defects
3 describe and explain how to separate white light into its component colours
4 differentiate between primary and secondary colours
5 outline the components of the electromagnetic spectrum.

Background information

Light is a form of energy that stimulates vision. Nature has made a massive provision through the sun to cater for this energy need during the day.

Humans have directed their efforts at providing light especially in the night through the use of electricity bio fuels, cells and batteries.

Science and technology has made tremendous stride in the field of electronics to facilitate effective communication, entertainment and storage and processing of data.

In this section we will deal with light and heat as forms of energy.

Sight is synonymous with light. The Earth is lit by the Sun. Plants use light for photosynthesis. Solar energy is used as an alternative source of energy. The need for light has led to the invention and development of many other sources of light for use at home, in workplaces and other places.

The invention of optical instruments has enhanced research, and has led to the invention of many instruments in areas such as communication, exploration and education.

Light is a source of energy that cannot be separated from the development of society. Optical inventions have provided us with many benefits, including better education and health delivery systems, through the use of visuals such as film shows and television; and also through the use of X-rays, and optical instruments for research.

In Junior High School we discussed the natural and artificial sources of light. We also realised that light travels in a straight line in any medium of uniform density. The path of light refracts as it leaves one medium into another of different optical density.

Again, we discussed how light behaves when it comes into contact with transparent, translucent and opaque materials.

We discussed how light reflects on striking smooth shiny surfaces such as a mirror, the surface of water and polished surfaces.

We also discussed how images are formed in plane mirrors and found out that the images formed in plain mirrors are of the same size as the object in front of the mirror. The distance of object from the object to the mirror is equal to the distance of image from the mirror to the image; we realised that the image is laterally inverted and virtual.

Light makes it possible for humans and other animals to see. The structure of the mammalian eye has components which facilitates and also controls image formation to allow for sight.

Reflection of light

Objects such as a mirror or the Moon do not produce light; they are non-luminous objects. Objects that are

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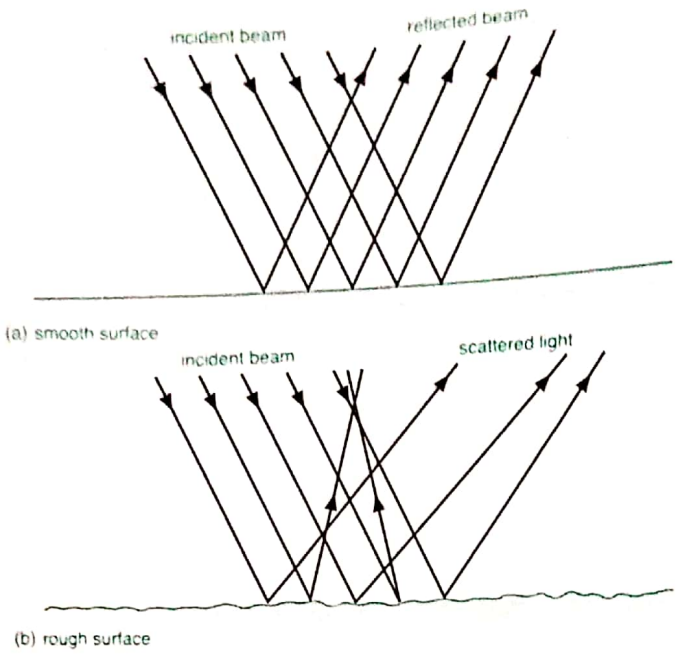


Fig 3.47 Regular and diffused reflections.

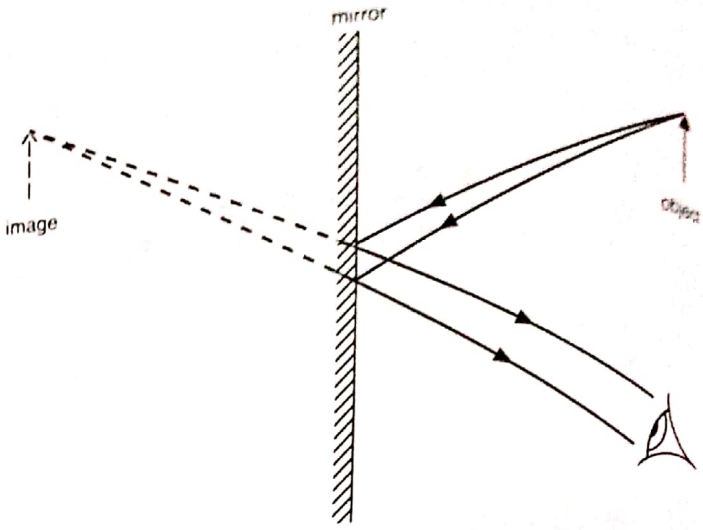


Fig 3.48 Position of the image in a plane mirror.

non-luminous are seen only when luminous objects (objects that produce light) throw light on them. As we have seen, when light shines on a non-luminous object the light may be absorbed, reflected or allowed to pass through. It is the reflected portion of the light that allows us to see the object.

The objects that reflect the most light have smooth or shiny surfaces: for example shiny cooking utensils, polished surfaces of furniture, mirrors, or the surface of water.

The eye is the organ of sight for people and many animals. We see an object when light reflected from it is received by the eye and nerve impulses are transmitted to the brain. Most objects reflect light from luminous objects such as the sun, electric bulbs and lamps into our eyes. When no light is reflected an object appears black. People cannot see in darkness because there is no light to be reflected from objects into the eye.

Almost all the light that falls on polished mirrors is reflected. Smooth objects, such as polished mirrors, reflect light in a regular fashion. This is called **regular reflection**. All the rays in the beam of light are reflected in the same direction (Figure 3.47(a)).

Matt surfaces, such as frosted glass mirrors coated with dust, and surfaces with projections (rough surfaces), such as terrazzo walls, produce **irregular reflections**. An irregular reflection is also called a **diffused reflection**. Such reflections are scattered. When light shines on such a surface the reflected rays are diffused or scattered in different directions (Figure 3.47(b)). If an image of an object is formed as a result of diffused reflection it is not clearly defined, and cannot be seen well. Frosted glass louvre blades are used in washrooms to prevent people from outside seeing through them.

Formation of images

An image is formed on a surface by the convergence of the rays of light from the object producing it. Generally speaking, images are formed by mirrors and lenses. Shiny smooth surfaces produce well-defined images.

An image can be real or virtual. **Real images** can be formed on a screen. Converging (concave) mirrors can produce real images. Real images can be magnified or diminished (made smaller). A plane mirror produces a clear image, but that image cannot be received on a screen. The image appears to be behind the mirror. Such an image is called a **virtual image**. Plane mirrors produce virtual images.

There are three main types of mirror that form images:

- plane mirrors (e.g. dressing mirrors)
- converging (or concave) mirrors (e.g. shaving mirrors)
- diverging (or convex) mirrors (e.g. driving mirrors).

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Plane mirrors

If you stand in front of a mirror, you see an image of yourself. The image is:

- erect (upright)
- the same size as the object producing it
- as far behind the mirror as the object is in front
- laterally inverted (the left side appears as the right side and vice versa)
- on the same normal to the mirror as the object (a line joining the object and the mirror will cross at right angles).

See Figure 3.48.

ACTIVITY 1 Investigating the image formed in a plane mirror

1 Stand a strip of plane mirror on a horizontal line near the middle of a sheet of paper.

2 Stand an optical pin upright and firm 10 cm in front of the mirror.

3 From the right-hand side use two optical pins to locate the image of the object in the mirror. (The two new pins should line up with the reflected image so that the three pins appear in a straight line.)

4 Repeat this process from the left-hand side of the mirror.

5 Link the pairs of pin marks with two line segments and follow them back behind the mirror position until they meet. This is the position of the image.

6 Join the object and image positions with a line segment. At what angle does this line segment meet the mirror?

7 Measure the distances of the object and the image from the mirror. What do you notice about these lengths?

8 Repeat the whole experiment with the object pin 5 cm from the mirror and compare the object and image distances.

ACTIVITY 2 Investigating reflections in a plane mirror

1 Stand a strip of plane mirror on a horizontal line on a sheet of paper.

2 Draw a line on the paper perpendicular to the horizontal line. This is the normal to the mirror.

3 At the left-hand side of the normal line measure an angle of 20° and link it with a line segment to the point where the normal meets the mirror.

4 Place two pins on the line so they are upright and firm.

5 From the right-hand side use two optical pins to locate the direction of the reflected ray in the mirror. (The two new pins should line up with the reflections of the original pins seen in the mirror so that all four pins should be in line when viewed from the right-hand side.)

6 Link the two pin marks on the right-hand side of the normal with a line segment to the point where the normal meets the mirror.

7 Measure the:
   a) angle of incidence (the angle between the line on the left-hand side and the normal)
   b) angle of reflection (the angle between the line on the right-hand side and the normal).

8 Repeat the experiment for the following angles:
   30°, 40°, 50°, 60° and 70°.

9 Plot a graph of angle of incidence against angle of reflection.

10 What does your graph show about the angles of incidence and reflection?

Plane mirrors obey the following two **laws of reflection**:

> The incident ray, the reflected ray and the normal drawn at the point of incidence all lie on the same plane.
>
> The angle of incidence is equal to the angle of reflection.

Curved mirrors

These are also called **spherical mirrors** because their shape is part of a sphere. There are two types of curved mirror (Figure 3.49). If the reflecting, silvered side curves inwards it is a **concave mirror**. If the silvered side curves outwards, it is a **convex mirror**.

Imagine that you could make a spherical mirror by cutting it from a complete sphere of mirrored glass. The centre of that imaginary sphere is the mirror's **centre of curvature**. It is labelled with the letter C. The curved piece of mirror itself has a mid-point that is referred to as the **pole**, and is labelled with the letter P. The line that passes through the pole of the mirror and its centre of curvature is called the **principal axis**. The principal focus of the mirror – the point where all reflected rays from the mirror converge, or from which they appear to

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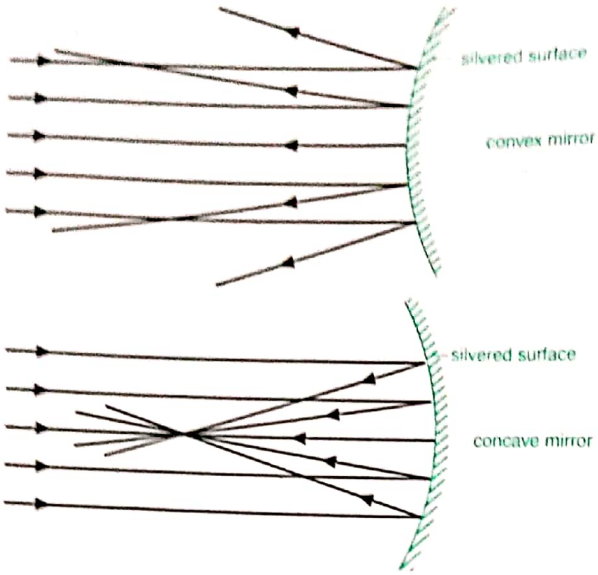


Fig 3.49 Spherical mirrors.

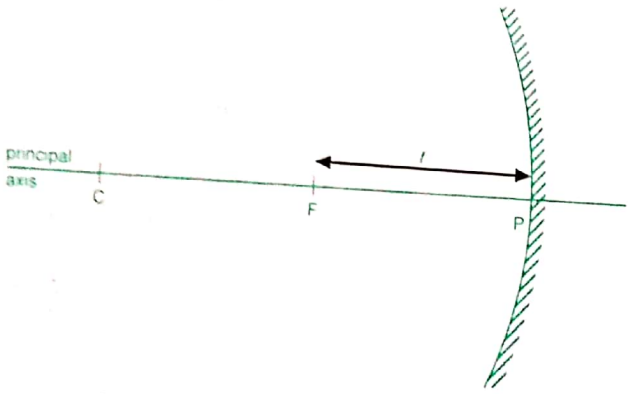


Fig 3.50 The conventions used in a ray diagram for a spherical mirror.

diverge – is called the **focal point**. This point is always halfway between the centre of curvature and the pole. It is labelled with the letter F. The distance between the focal point and the pole is called the focal length and is labelled with the letter f (Figure 3.50).

We can locate the position of an image in a concave mirror by drawing at least two of the following three rays:

- a ray passing through the centre of curvature, reflected back along the same path
- a ray parallel to the principal axis, reflected through the principal focus
- a ray passing through the principal focus, reflected parallel to the principal axis.

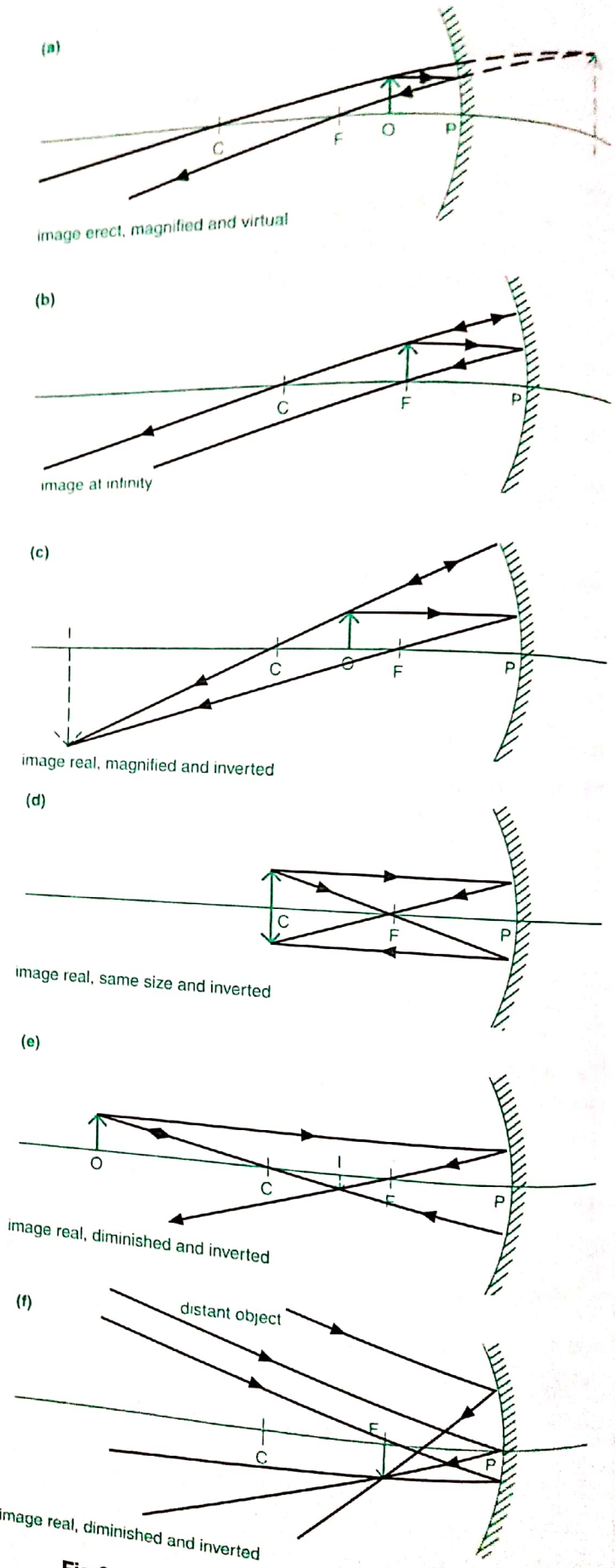


Fig 3.51 Images formed by a concave mirror.

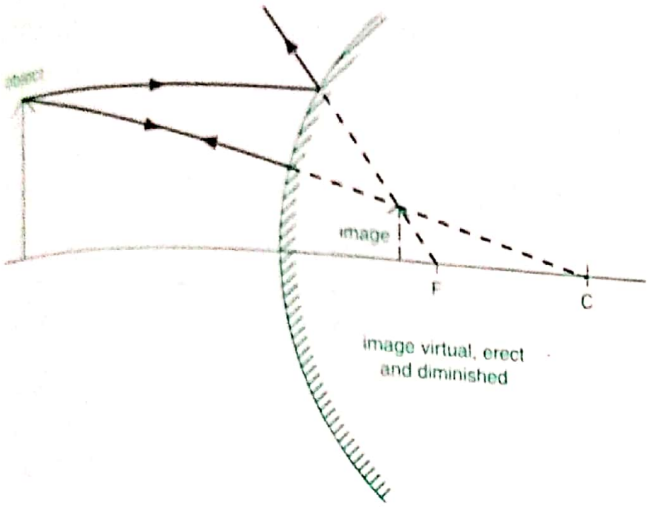


Fig 3.52 Image formed by a convex mirror.

Formation of images by concave mirrors

A concave mirror can produce different sorts of images depending on the position of the object. These are shown in Figure 3.51.

Formation of images by convex mirrors

A convex mirror produces only one sort of image no matter where an object is placed in front of it (Figure 3.52). This image is:

- virtual (it cannot be shown on a screen placed in front of it)
- diminished (it is smaller than the object producing it)
- erect (upright).

A convex mirror gives a wider field of view than a plane mirror of the same size. This is why driving mirrors are usually convex. For the same reason, busy shops have convex mirrors at various points so that the staff can keep an eye on the goods and watch out for shoplifters.

Refraction of light

When a light ray travels from one substance (or **medium**) to another of different optical density, at an angle of incidence greater than 0°, its direction changes abruptly. The light is refracted on entering or leaving the second medium. For example, when light travels from air into water its path is refracted as it enters the water. If it leaves the water and emerges back into the air it is refracted again.

Light is always refracted towards the normal at the point of incidence if the second medium is denser than the first, and away from the normal at the point of incidence if the first medium is denser than the second (Figure 3.53).

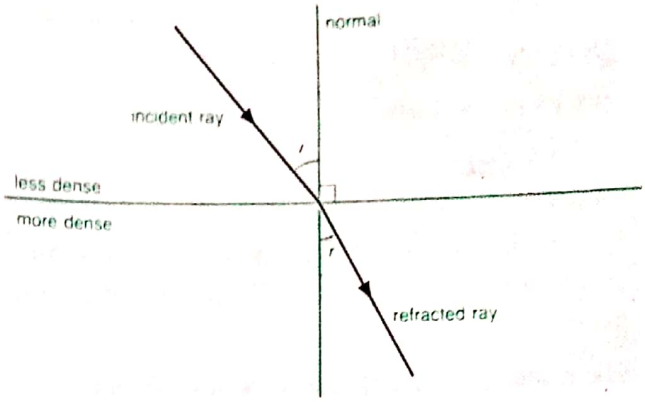


Fig 3.53 Refraction of light rays.

ACTIVITY 3 Finding out about refraction of light

1 Place a pencil into an empty beaker, or a broomstick into an empty bucket, at an angle less than 90°. Record what you see.
2 Pour water into the beaker or the bucket until it is three-quarters full. Record what you see.
3 Insert the pencil or broomstick into the water at 90°. Now what do you see?
4 *Work in groups* to discuss and summarise your observations.

For any two particular media there is a constant relationship between the sine of the angle of incidence and the sine of the angle of refraction, which is called the refractive index.

Why does refraction occur? The speed of light is constant within a uniform medium such as air, water or glass, but it is different for different media. So a light ray bends at the interface between two media because its speed changes as it passes from one medium into the other. The speed change depends on whether the second medium is more, or less, optically dense. For example, when light travels from air into glass, which is optically denser, the speed of the light decreases. Conversely, the speed increases when the light moves from glass into air.

We can see refraction of light in many real-life situations. For example, it makes ponds appear shallower than they really are. It makes the stars appear to twinkle as their light passes through the atmosphere. Refraction is used in

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lenses: both in camera lenses for taking pictures and in the lenses of projectors for showing films on a screen.

Laws of refraction

There are two laws of refraction:

> The incident ray, the refracted ray and the normal drawn at the point of incidence all lie in the same plane.
>
> The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any given pair of media. This is **Snell's law of refraction.**

Lenses

Lenses are widely used in the construction of cameras, spectacles, binoculars and projectors. They are made of either glass or plastic, and come in two forms:

- converging lenses
- diverging lenses.

Lenses are concerned with the refraction of light in particular ways. A **converging lens** (Figure 3.54(a)) causes light rays that are parallel to its principal axis to converge at a point. A **diverging lens** (Figure 3.54(b)) causes parallel rays near the principal axis to diverge.

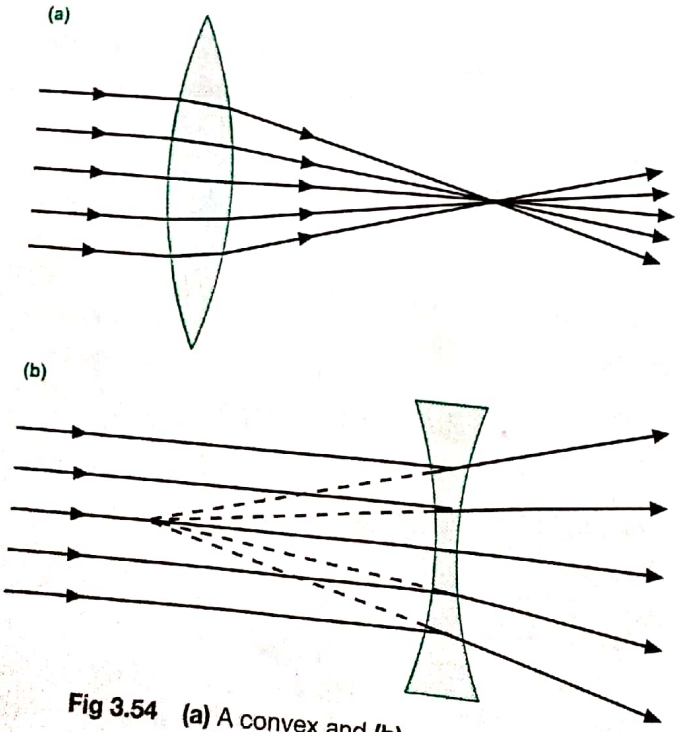


Fig 3.54 **(a)** A convex and **(b)** a concave lens.

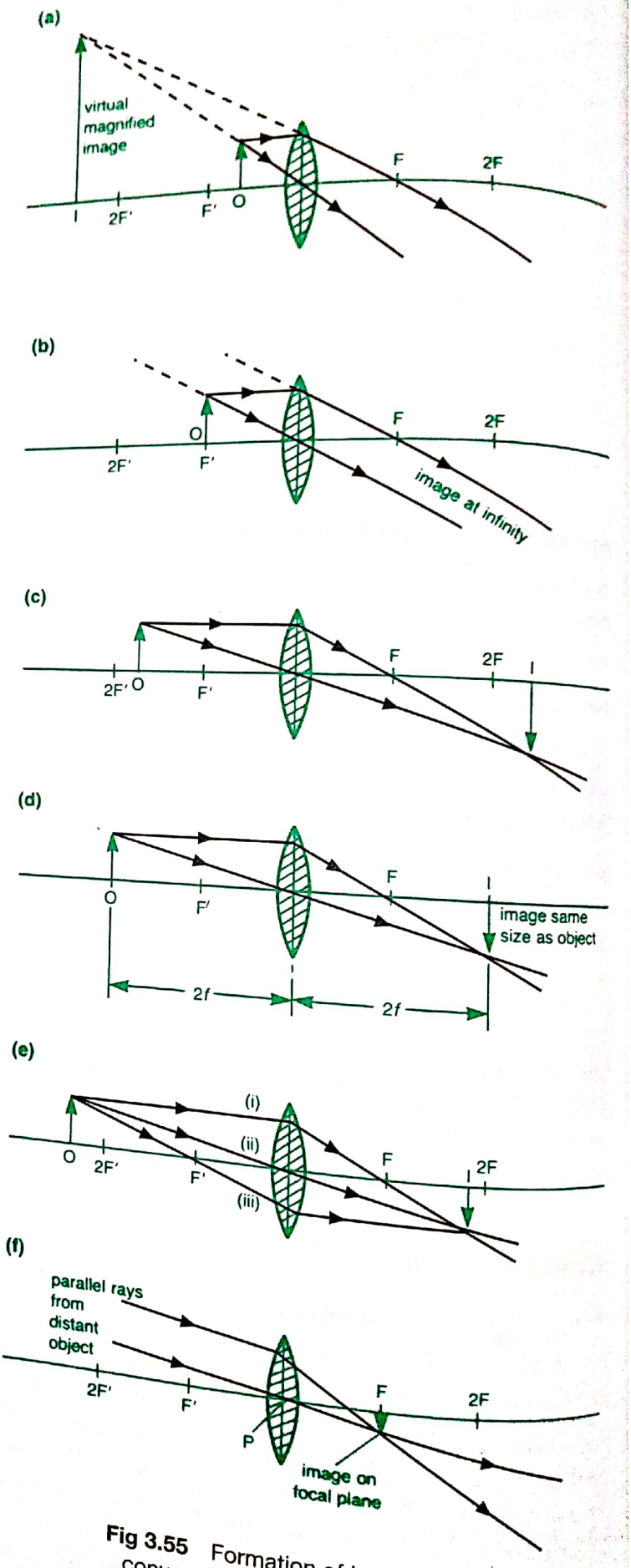


Fig 3.55 Formation of images by a converging lens (see Table 3.13).

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Converging lenses may be **biconvex** (two curved surfaces) or **planoconvex** (one flat surface and one curved one). Similarly diverging lenses may be **biconcave** or **planoconcave**. A convex lens is thicker at its centre than at its edges, whereas a concave lens is thinner at its centre than at its edges. However both a convex and a concave lens may have one convex and one concave surface.

Formation of images by converging lenses

The nature and position of the images formed by a converging lens depend on the position of the object, as shown in Figure 3.55 and listed in Table 3.13.

Formation of images by diverging lenses

An image formed by a diverging lenses is always upright (erect), diminished and virtual. The image is also on the same side of the lens as the object, and between the object and the lens (Figure 3.56).

Table 3.13 Positions of objects and their images in a converging lens

Position of object	Position of image formed	Features of the image	Instrument that applies it
between focal point and optical centre	behind the object, on the same side of the lens	virtual magnified erect	magnifying glass and microscope
on principal focus	infinity	real magnified inverted	searchlight and spotlight
between focal point and twice focal length from the lens	beyond 2*f*	real magnified inverted	photographic enlarger, cine-projector
at twice the focal length from the centre of the lens	at 2*f*	real same size as object inverted	terrestrial telescope
beyond twice the focal length	between focal point and 2*f*	real diminished inverted	cameras
infinity	focal point	real diminished inverted	

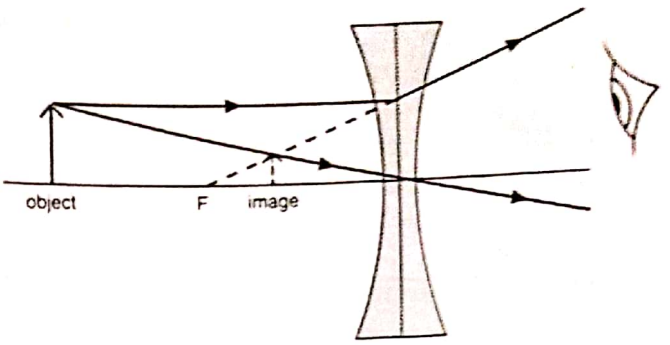


Fig 3.56 Image formed by a diverging lens.

Formation of mirages

Mirages often appear during very hot weather, especially on tarmac roads or sandy areas. The ground itself is very hot, and this makes the air close to the ground very hot. Rays of light from above are continuously refracted as they get nearer the ground, as hot air is less dense than cool air. They are then refracted upwards by cooler, denser air into the observer's eye. The observer may see an image of the sky, which appears as a pool of water on the ground some distance in front (Figure 3.57). This is a result of total internal reflection.

The human eye

The human eye, as an example of the mammalian eye, is an organ that is receptive to light and stimulates the sense of vision. The human eye perceives and can accommodate an image from as near as a point of 25 cm to infinity when everything about the eye is normal.

Each eye is situated in a hollow (**orbit**). The eye is protected by a thin membrane (**conjunctiva**) and by the eyelids, eyelashes and lachrymal (tear) glands. The muscles that move the eyes are precisely coordinated so that both eyes work together and are always directed at the same object.

The parts of the human eye are shown in Figure 3.58, which is a vertical cross-section through the eye:

- **Sclerotic** – outer coat. This is protective and composed of tough fibres.
- **Cornea** – continuous with sclerotic. This is transparent and therefore allows light through. The greatest refraction of light in the eye occurs here.
- **Choroid** – contains blood vessels, and supplies the cells with food and oxygen and carries waste away.

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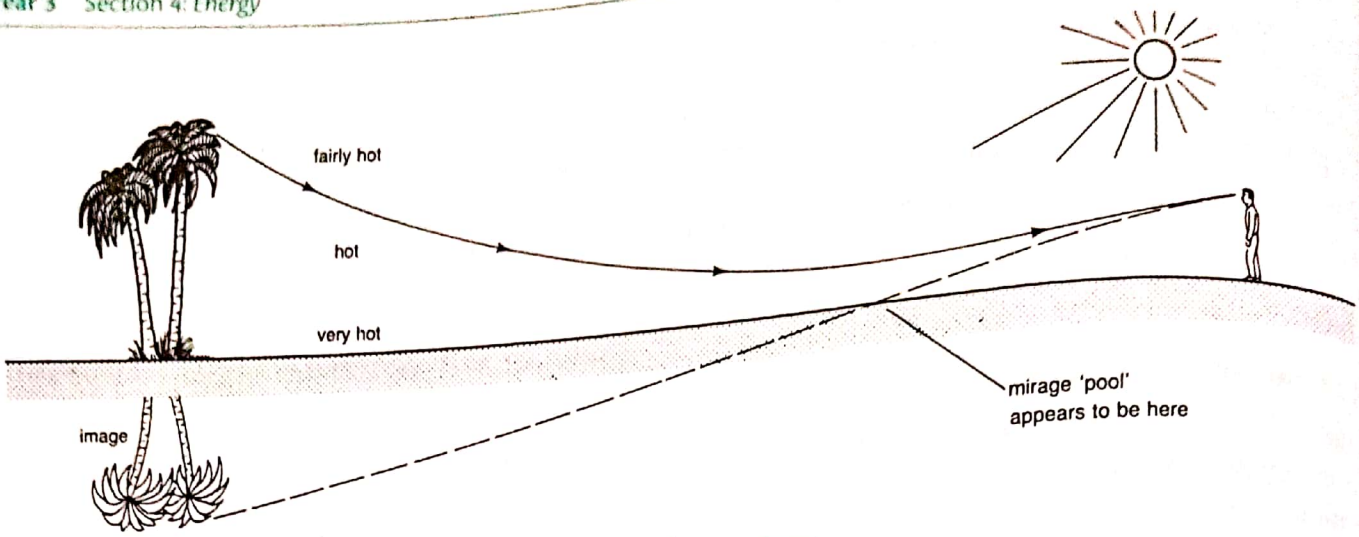


Fig 3.57 Formation of a mirage.

It also contains a pigment that prevents internal reflection of light.

- **Aqueous humour** – fluid in front of the lens. This is similar to blood plasma. It carries food and oxygen to the cornea and lens. It also helps to maintain the shape of the eye. It is constantly drained and replaced.
- **Lens** – a transparent, flexible body that sits behind the iris and focuses light on the retina. The muscles of the ciliary body both hold the lens in place and contract and relax to change its shape, allowing it to focus.
- **Vitreous humour** – jelly-like material behind the lens. This maintains the shape of the eyeball.
- **Iris/pupil** – the iris is the coloured part of the eye. It has the pupil in the middle. The size of the pupil is regulated by the radial and circular muscles in the iris; it controls the amount of light allowed into the eye.
- **Ciliary body/ciliary muscle/suspensory ligaments/lens** – these are all involved in focusing light from objects that enters the eye onto the retina.
- **Retina** – this is at the back of the eye. It is packed with light-sensitive cells (rods and cones) which are connected to the brain by the optic nerve.

ACTIVITY 4 Investigating the parts of the mammalian eye

1 Using a chart or a model, identify the parts of the eye shown in Figure 3.58.
2 Draw and label the parts of the eye.
3 Write down the functions of the parts of the human eye.

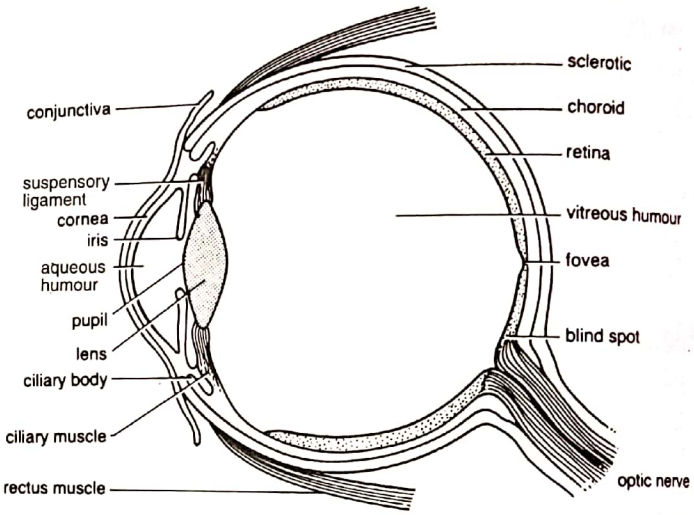


Fig 3.58 Diagram of vertical cross-section through the human eye.

How the eye sees

The transparent cornea reflects light rays into the pupil. The iris acts as a diaphragm and regulates the amount of light that enters the eye. On bright sunny day the iris contracts and the pupil becomes small. In dark rooms and in the night the iris expands and the pupil allows more light into the eye.

The lens forms an inverted, diminished image on the retina, the nerve cells which are sensitive to light impulses transmit light messages to the brain for interpretation.

Persistence of vision

When the nerve fibre in the retina is stimulated by light it does not immediately cease. It continues (persist) for

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about 0.1 seconds and during this time frame the image is still seen.

As a result a rapid moving light is seen as a line of light. Whenever vision is stimulated the persistence of vision explains how the impression of continuous motion is used in video production and cinema.

Vision of near objects

The normal eye can see objects from a near point of 25 cm to infinity, the nearest point at which the eye can see an object in a relaxed state is called the near point. The near point is called the least distance of distinct vision. This distance varies with age and increases as one gets older.

An eye sees an object at infinity in a relaxed state.

Power of accommodation

The focal point of the eye lens is equal to the length of the eyeball when the crystalline lens is thin. The focal lens is reduced when the lens becomes more convex.

Under such conditions a real, inverted and diminished image is produced on the retina. The process is called the power of accommodation. Power of accommodation is the ability of the eye to change the focal length of the eye lens.

Defects of vision

As one gets older defects arise in the structure of the eye which affects the ability of the eye to form an image on the retina. Common defects of the human eye include long-sightedness and short-sightedness. Other defects include presbyopia (or lack of accommodation) and astigmatism.

Long sight (hypermetropia)

People who are long-sighted can see distant objects clearly but not near objects. This is because either the eyeball is too short from front to back, or the eye lens lacks power (its focal length is too long). In either case, light from near objects is focused behind the retina because the focal length of the eye lens is too long for the length of the eyeball.

Long sight can be corrected by spectacles or contact lenses fitted with converging lenses (Figure 3.59).

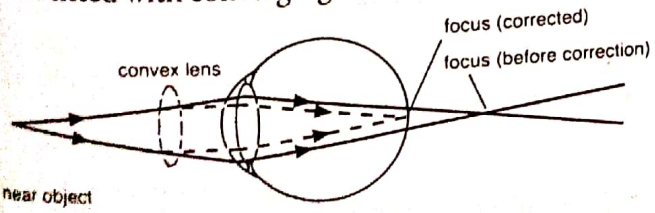


Fig 3.59 A converging lens is used to correct long-sightedness.

Short sight (myopia)

People who are short-sighted can see near objects clearly but not distant objects. This is because either the eyeball is too long, or the lens is too powerful (its focal length is too short and causes too much refraction). Parallel rays from distant objects are focused in front of the retina because the focal length of the lens of the eye is shorter than the length of the eyeball.

Short sight can be corrected by using diverging lenses fitted in a pair of spectacles or contact lenses (Figure 3.60).

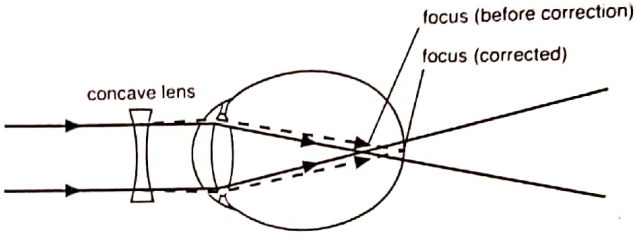


Fig 3.60 A diverging lens is used to correct short-sightedness.

Presbyopia (defective accommodation)

This is a visual condition which becomes apparent especially in middle age and in which loss of elasticity of the lens of the eye causes defective accommodation and inability to focus sharply for near vision. Converging reading glasses are needed to correct the defects: a converging lens reduces the distance of near point and also reduces the distance of far point.

Astigmatism

The cornea and the lens of a human eye are spherical in shape. As a result of old age or disease the eye surface of some people are elliptically shaped. Such a distortion on the surface of the eye is referred to as astigmatism. As a result of the distortion in the curvature of the parts of the cornea and the eye light rays from a point object cannot be focused to a signal point. Such a defect is corrected by using a lens to reorientate the eye to focus an object properly on the retina.

Dispersion of light

The light that comes from the Sun (white light) and other luminous light sources is not one colour but a mixture, or **spectrum**, of colours. Traditionally, white

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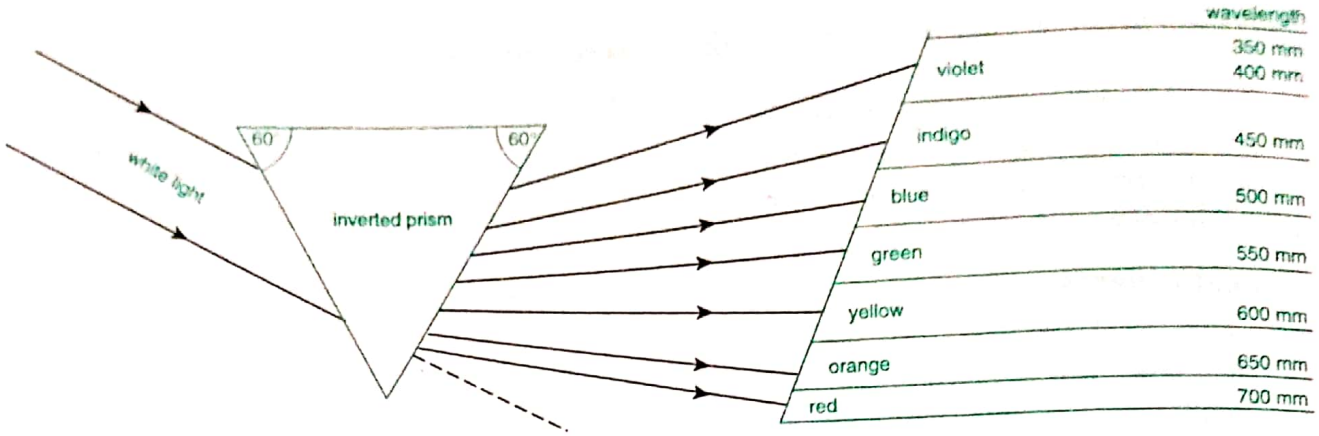


Fig 3.61 Dispersion of white light by a triangular prism.

light is considered to be composed of seven colour bands – red, orange, yellow, green, blue, indigo and violet (ROYGBIV) – although the visible spectrum is continuous and there are many different hues between these seven colours. Visible light appears white when it moves in a uniform optical medium. When light passes from one medium to another, such as air through water, the colours separate from each other.

Light is part of a much bigger family of waves called **electromagnetic radiation**. Light is the portion of the electromagnetic spectrum that is visible to the eye. The different colours of light called the **component colours** in the visible spectrum have different wavelengths and different frequencies.

Above the violet band are other types of radiation of shorter wavelength that cannot be seen by the human eye. These include ultraviolet radiation, X-rays and gamma rays. Below the red band are other types of radiation of longer wavelength which are not visible to the human eye. These include infrared radiation, microwaves and radio waves.

All the colours of the visible spectrum travel at the same speed in a vacuum, but the different coloured lights travel at different speeds in all other materials. When light travels from air into optically dense media such as water or glass, the refraction that occurs causes the colours to separate as each colour changes direction by a different angle. In this way, a spectrum of what is commonly called rainbow colours is formed.

When light travels through an equilateral triangular prism, clouds, or water in a transparent polythene bag, or when a plane mirror reflects light from a bowl of water onto a screen, the different colours of light can be identified. Red light is the least deviated and violet is the most deviated light colour. The separation of white light into its component colours is called **dispersion**. The colours and their wavelengths are shown in Figure 3.61.

ACTIVITY 5 Finding out how rainbow colours are formed from light

1 Collect the following apparatus from your teacher: a bowl; a plane mirror; some soap/detergent powder; some straws.

2 Half fill a bowl with water.

3 Place a plane mirror at an angle in the bowl of water.

4 Reflect the Sun's rays or torch light rays in the plane mirror to focus onto a white screen.

What do you see? Explain the cause of your observation.

Light can also be split up into its component colours when it passes through a thin film of transparent material, such as a soap bubble.

5 Use soap or detergent to prepare lather. Dip a straw or a paw-paw stalk or rubber tube into the soap.

6 Gently blow air into the straw or tube at the dry end so that large balls of soap bubbles shoot out.

7 List the various colours that you see on the soap bubble.

8 Connect a rubber hose to a tap and turn the tap on (outdoors!).

9 Turn your back to the Sun and spray the water in the air.

10 Record what you see through the droplets of sprayed water.

11 List as many different methods as possible to disperse white light into its different colours, and write a report on it for class discussion.

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Primary colours of light

We can see in colour because of cells in the retina of the eye called **cones**. There are three types of cone, sensitive to one colour only: red, green or blue. These are **primary colours of light**. The brain combines the signals sent from all the cones to produce the sensation of colour. When all three types of cones are stimulated equally the sensation is of white light. We can produce light of any colour by mixing lights of these three primary colours in different proportions. This process is called **colour mixing by addition**. It is how the colour is produced on a television screen, where glowing phosphor dots of red, green and blue combine. Pairs of colours that produce white light, such as orange and blue, are called **complementary colours**.

When we shine light on an object, it absorbs some of the wavelengths and reflects others. We see the object as coloured because of the mixture of wavelengths in the reflected light. So, for example, a red object absorbs all wavelengths falling on it except those in the red end of the spectrum. This means that a red object viewed in white light will appear red, but if the same object is viewed in blue light it will appear black as it will absorb the blue light and so not reflect any light.

Secondary colours of light

We can combine the primary colours of light – red, green and blue – to produce the **secondary colours** shown in Table 3.14. These three colours – yellow, magenta and cyan – are used as primary colours in colour printing. For example, yellow printing ink absorbs blue light and reflects red and green. Cyan printing ink absorbs red light and reflects blue and green. So if we mix yellow and cyan inks together, the mixture will absorb both blue and red light, and will reflect only green – so the mixture of inks will appear green. By mixing the three secondary colours together in different proportions we can produce almost any colour except white.

Table 3.14 Formation of secondary colours

Primary colours	Secondary colours
red + green	yellow
red + blue	magenta (purple)
blue + green	cyan (blue-green)

This process is called colour mixing by subtraction. Artists use it when they mix their paints to produce different colours, and the dyeing industry uses it when pigments are mixed together to produce different colours of dyes.

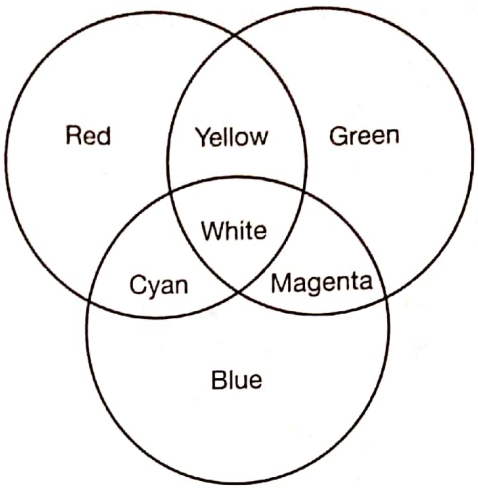


Fig 3.62

Mixing coloured light

When the primary colour combines with its corresponding secondary colour white is produced:

Red + cyan → white
Green + magenta → white
Blue + yellow → white

Electromagnetic spectrum

The electromagnetic spectrum is a family of waves, all caused by vibrations of the electrically charged and magnetic particles within atoms and molecules. All electromagnetic waves travel approximately 3×10^8 ms^{-1} in a vacuum and almost this fast in air. They do not need a material medium through which to travel and they all display reflection, refraction and diffraction behaviour as described above.

The visible radiant waves (light) is made up of colours red, orange, yellow, green, blue, indigo and violet (ROYGBIV) which travel together in a medium of uniform optical density such as air.

The wavelengths and methods of detection of waves in the electromagnetic spectrum are summarised in Figure 3.63.

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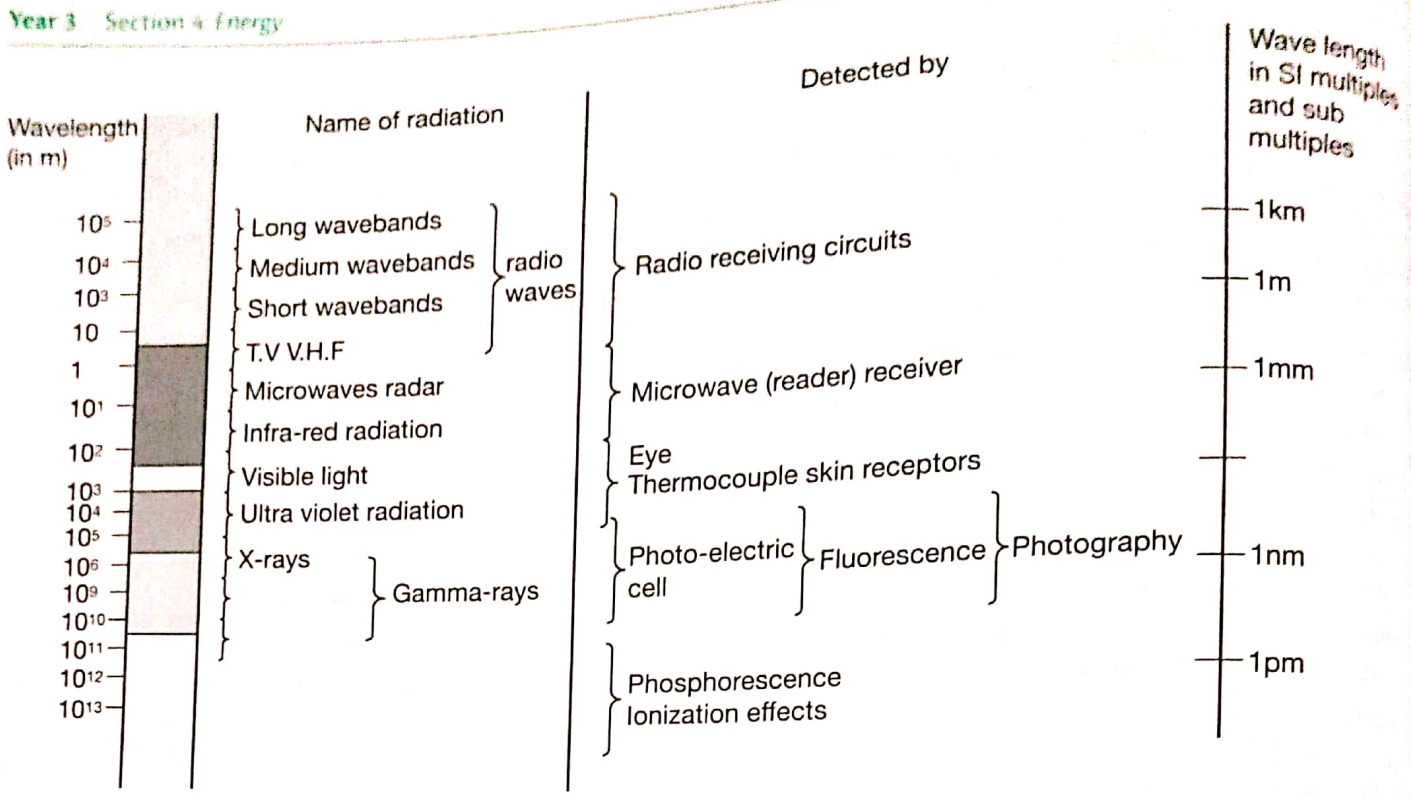


Fig 3.63 The electromagnetic spectrum.

Selective absorption of colours

When the white sunlight falls on a green leaf the leaf absorbs all other colours and reflects the colour green to the observer. The colours which a body reflects from the sunlight to the eye are the colour of this body and it is the colours of the visible light which it reflects to the eye. Lack of light will produce darkness since no colour is reflected to the eye.

Invisible components of the electromagnetic spectrum

The electromagnetic spectrum consists of waves that cannot be perceived by the human eye and the visible band of waves. The invisible band of waves include Hertzian waves (radio waves), infrared waves, ultraviolet radiation, X-rays and gamma rays.

Radio waves and infrared waves have long wavelengths that do not allow the human eye to perceive them. Ultraviolet radiation, X-rays and gamma rays have wavelengths that are too short to be perceived by the human eye.

Uses of electromagnetic waves

- Gamma rays are used to detect cracks in metals to irradiate objects and to sterilise hospital equipment.
- X-rays are used to form images of bones in humans and to destroy cancerous tissues in cancer patients.
- Ultraviolet (UV) is used to brighten dyes and paints.
- The visible light in the electromagnetic spectrum allow humans and other animals to see.
- Infrared radiation is the medium in which heat energy travels. It provides vitamin D in humans and warmth to living organisms.
- Microwave radiation helps in transmission and reception of information through radios and televisions, and for cooking. Microwave radiation is hazardous when allowed to pass through human bodies.
- Radio waves induce a current in receiving aerials and help in transmission of messages by radio, television and other communication gadgets.

Self check

For questions 1 to 14, choose the letter that refers to the correct option.

1 Shadow formation shows that light rays
A can be diffused
B travel in straight lines
C can be refracted
D can be reflected

2 Which of the following statements is correct about the laws of refraction of light?
A The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane
B The angle of incidence is equal to the angle of refraction
C The angle of incidence is always greater than the angle of refraction
D Sine *i* is always equal to sine *r*

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3 When an object is placed beyond the focus of a diverging lens, the image formed will be
A inverted and enlarged
B inverted and diminished
C erect and diminished
D erect and enlarged

4 When light is made to pass through a triangular prism, the light is split up into different colours. The colours at the edges of the spectrum are
A violet and yellow
B violet and blue
C green and violet
D red and violet

5 Which of the following is not a primary colour of light?
A red
B blue
C yellow
D green

6 Regular reflection of light occurs when the reflector is
A curved with a rough surface
B smooth with a shiny surface
C rough with a black surface
D rough with a white surface

7 A total eclipse of the sun is seen when the observer is in the
A umbra region of the sun's shadow
B penumbra region of the moon's shadow
C umbra region of the moon's shadow
D umbra region of the Earth's shadow

8 Which of the following would produce a virtual, erect and enlarged image?
A a converging lens with the object at its focus
B a diverging lens with the object at a distance between its focal length and twice its focal length
C a converging lens with the object at a distance less than its focal length
D a diverging lens with the object at a distance less than its focal length

9 A convex mirror is used as a driving mirror because it has a wide field of view and it forms images that are
A diminished and real
B diminished and virtual
C magnified and real
D magnified and virtual

10 The colour of light depends on its
A amplitude
B intensity
C velocity
D frequency

11 A pencil is placed vertically between the pole of a concave mirror and its focal point. The image will be
A real, enlarged and erect
B virtual, erect and enlarged
C virtual, inverted and enlarged
D real, enlarged and inverted

12 All of the following are secondary colours of light except
A cyan
B magenta
C red
D yellow

13 A non-luminous object such as the moon can be seen when the light falling on it is
A absorbed
B diffracted
C reflected
D refracted

14 When red light and green light are mixed the resulting colour is
A blue
B cyan
C magenta
D yellow

15 State the colour produced when each of the following pairs of coloured lights are mixed:
(i) red and blue
(ii) magenta and green
(iii) blue and green.

16 Explain the following terms:
(i) shadow
(ii) umbra
(iii) penumbra.

17 a) Define dispersion of light.
b) Explain the formation of rainbows in the sky.

18 Which colour combinations will be used in printing the Ghanaian flag?

19 Under what conditions is light said to be regularly reflected?

20 What are the characteristics of an image formed in a plane mirror?

21 What is the function of the aqueous and vitreous humour in formation of image on the retina?

22 Define the following eye defects:
(i) myopia
(ii) hypermetropia.

Using a labelled diagram show how each of them is corrected.

23 Explain the following terms:
(i) dispersion of light
(ii) secondary colours
(iii) complimentary colours.

24 Describe an experiment you could use to explain dispersion of visible light to a Junior High School Form 3 student.

25 What is meant by selective absorption of light?

26 Name the type of lenses used to correct:
(i) long-sightedness
(ii) short-sightedness

27 Draw the structure of the human eye and relate the components with their functions.

28 Draw a diagram to show how a triangular prism disperses light.

29 What are the advantages and disadvantages of X-ray radiation?

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2 Heat energy

Learning objectives

After studying this unit you should be able to:

1 describe the nature and sources of heat energy
2 describe the modes of heat transfer
3 explain the concept of temperature and how it is measured
4 discuss the effects of heat
5 explain how heat causes change of state of matter.

Background information

Energy is a concept that can best be explained through its functions and effects. Matter is anything that has mass and occupies space. Whenever changes occur in matter, heat is involved. Heat is therefore one of the basic needs for daily activities. For example, heat energy is used for cooking, for melting, for boiling, to keep the body warm and for domestic and industrial activities.

Heat energy can be converted into other forms of energy, such as light and electricity. Both machines and living things depend on a certain quantity of heat energy for them to function effectively.

The nature of heat

Heat is a form of energy. If two objects, one hotter than the other, are placed together, heat will be transferred from the hotter object to the colder one until both objects attain the same degree of hotness or coldness (temperature). The two objects with the same temperature are said to be at **thermal equilibrium**.

Other forms of energy may be converted into heat energy. Consider what happens when we light a fire to prepare food. When we strike a match (Figure 3.64), friction raises the temperature of the match head. Heat is immediately provided for a chemical reaction to take place, which produces further heat energy to raise the temperature of the match head sufficiently for it to catch fire (ignite). When the burning match is put to pieces of paper, or to palm nut pulp between firewood, further chemical reactions produce heat – enough heat for domestic and industrial purposes.

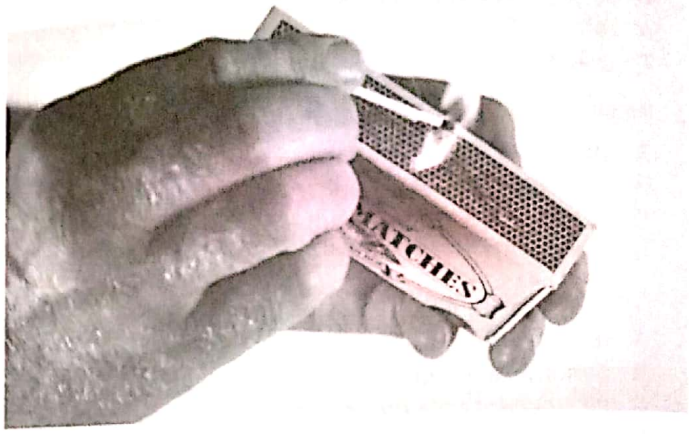


Fig 3.64 Kinetic and chemical energy are converted into heat energy when a match is struck.

Sources of heat include:

- the Sun
- fire
- friction
- fossil fuels
- electricity
- chemical reactions
- nuclear reactions.

Measuring heat

A cupful of boiled water is hot: its temperature is high, and it can cause scalds on the skin. Water from a pond

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is colder than the cup of boiled water, but a pond full of water or a river contains more heat energy than the cup of boiled water. Why? The water in the pond has less heat energy in each litre of water, than that in the cup, but there is much more of it. Similarly, if we place a large bowl full of water at 80°C and a small cup full of water at the same temperature in the same room, the bowl of water will have to lose more heat than the cup of water before their temperatures both drop to that of the room. The larger the mass of a substance, the more heat is needed to raise its temperature. Similarly, more heat is lost as a larger mass cools. Heat can therefore be thought of as the quantity of thermal energy that a body contains. Heat flow is often represented by the letter Q.

The quantity of heat contained in a body depends upon:

- the nature of the body
- the mass of the body
- the temperature of the body.

The SI unit of heat is the **joule**, and has the symbol J. Larger quantities of heat are often expressed in kilojoules (kJ) or megajoules (MJ). Before SI units were introduced heat was measured in calories. This term comes from *calor*, the Latin word for heat, which still appears in words such as 'calorimeter' and 'calorific value' (1 calorie = 4.18 J).

A body is in **thermal equilibrium** with its surroundings if no heat enters it or leaves it, so that all its parts are at the same temperature as the surroundings.

How heat flows

Heat can be transferred within solids, fluids (liquids and gases) and through a vacuum.

In solids heat travels by a process called **conduction**. Conduction is the flow of heat through substances from a region of higher temperature to a region of lower temperature. In solids and liquid metals, heat conduction is mainly the migration of fast-moving electrons followed by collisions between these electrons and ions.

Heat is transmitted in fluids (that is, liquids and gases) by **convection**. In convection, the heat is transferred from hot regions to cooler regions by the movement of the fluid itself. Heat transfer through water, a liquid, is due not to conduction, but to convection.

ACTIVITY 1 Investigating conduction in metals

1 Clamp a 60 cm metal rod on the workbench.

2 With candle wax fix office pins at 10 cm intervals along the underside of the rod from one end to the other.

3 Using a candle or a spirit lamp, heat the metal rod from the free end. What happened to the office pins? Explain your answer.

Is there a way you can make the heat drop all the pins at the same time? If so, show how this can be done. If not explain why this cannot be done. Show the direction of heat transfer in the metal.

We look in more detail at the ways heat can be transferred in the section on 'Transfer of heat'.

Measurement of heat

Objects are considered hot because their particles have a high kinetic energy: that is, they are moving about rapidly. This energy is referred to as the **internal energy** and is increased by heating. Heating an object results in a change in its temperature and in its shape (expansion), and may result in a change in state. There may also be movement of internal energy within the object as a result of conduction and convection.

Heat is a form of energy and is measured in joules. Materials respond to energy changes in different ways. If we apply the same amount of heat energy to equal masses of different substances, we find that they do not all have the same change in temperature. The particles in each material may move at different speeds.

The ability of a body to absorb energy is called its **heat capacity**. Objects that do not change temperature much when heat is supplied have a high heat capacity. The heat capacity of an object depends on its size. Large objects will absorb more heat with small temperature changes. The nature of the material is also important, as stated above. The heat capacity is the number of joules of energy needed to raise the temperature of the body by one kelvin.

> The **heat capacity** of an object is the quantity of heat energy required to raise its temperature by 1 kelvin (1 K) or 1 degree Celsius (1°C).

The SI unit of heat capacity is J K^{-1} (or J $°C^{-1}$).

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Specific heat capacity

In practice it is usually more useful to quote the heat capacity of unit mass of a substance rather than try to deal with a different value for every object.

> The **specific heat capacity** of a substance is the heat energy required to raise the temperature of 1 kg of it by 1 K (or 1°C).

The symbol for specific heat capacity is c, and the unit is J kg^{-1} K^{-1} (or K kg^{-1} °C^{-1}). Table 3.15 lists the specific heat capacities of some common materials.

Table 3.15 The specific heat capacity of some materials

Material	Specific heat capacity, c J kg^{-1} K^{-1}
lead	126
zinc	385
copper	385
iron	460
cast iron	500
crown glass	670
aluminium	913
air	720
olive oil	1970
water	4200
ice	2100

From Table 3.15 we can see that 500 J of heat energy is needed to raise the temperature of 1 kg of cast iron by 1 K. By scaling this value it follows that 40 000 J of energy would be required to increase the temperature of 8 kg of cast iron by 10 K. In general:

Change in energy = mass × specific heat capacity × temperature change

$$Q = mc\Delta T$$

Worked example 1

How many joules of heat are given out when a piece of iron of mass 5 kg cools from 90°C to 30°C? (Specific heat capacity of iron = 460 J kg^{-1} K^{-1})

Solution

$$\begin{aligned} Q &= mc\Delta T \\ m &= 5\text{ kg} \\ c &= 460\text{ J kg}^{-1}\text{ K}^{-1} \\ \Delta T &= 90°\text{C} - 30°\text{C} = 60°\text{C} \\ Q &= 5\text{ kg} \times 460\text{ J kg}^{-1}\text{ K}^{-1} \times 60°\text{C} \\ &= 138\,000\text{ J} = 138\text{ kJ} \end{aligned}$$

Worked example 2

What is the final temperature of the mixture when 200 g of hot water at 80°C is added to 300 g of cold water at 5°C and thoroughly stirred? (Specific heat capacity of water = 4200 J kg^{-1} K^{-1})

Solution

Let the final temperature of the mixture be x°C.

Change in temperature of hot water = $(80 - x)$°C
Change in temperature of cold water = $(x - 5)$°C

Substituting in $mc\Delta T$:

Heat lost by hot water = heat gained by cold water

$$mc(80 - x) = mc(x - 5)$$
$$0.2\text{ kg} \times 4200 \times (80 - x) = 0.3 \times 4200 \times (x - 5)$$

Dividing both sides by 4200:

$$0.2\text{ kg} \times (80 - x) = 0.3 \times (x - 5)$$
$$16 - 0.2x = 0.3x - 1.5$$
$$17.5 = 0.5x$$
$$x = 35°\text{C}$$

A **calorimeter** is a thin-walled container used to hold liquids in heat experiments. It is often used in experiments to determine the specific heat capacity of materials.

To be sure of accurate results, you should take the following precautions:

- Avoid heat loss to or gain from the surroundings by covering the calorimeter in lagging materials such as a thick blanket, cotton wool or wood shavings.
- Transfer the hot substance quickly and carefully into the calorimeter.
- Avoid splashing any of the liquid since this may affect the values of the quantities being used.
- Stir the mixture carefully in order to distribute the heat energy evenly throughout the liquid.
- Note that when the liquid is very hot, heat causes the calorimeter and its lid to expand. This may result in the lid becoming loose, so that heat is lost to the surroundings.

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ACTIVITY 2 Measuring the specific heat capacity of a metal block

1 Measure the mass of a brass block (m_1).

2 Measure the mass of a clean, dry, copper calorimeter (m_2).

3 Half fill the calorimeter with cold water and measure the resulting mass to obtain the mass of the water (m_3).

4 Let the water stand for 5 minutes, to reach thermal equilibrium with the calorimeter. Then measure its temperature (T_1).

5 Suspend the brass block with a thread in a beaker of water, and heat until the water boils (100°C).

6 Quickly transfer the heated block into the water in the calorimeter, close it and stir gently.

7 Record the highest temperature reached by the mixture (T_2).

8 Calculate the specific heat capacity of brass as follows:

Heat loss by brass = Heat gained by water + calorimeter

$$m_1 \times c_1 \times (100 - T_2)$$

$$= m_3 \times c_3 \times (T_2 - T_1) + m_2 \times c_2 \times (T_2 - T_1)$$

where c_1 is the specific heat capacity of brass, c_2 is the specific heat capacity of water, and c_3 is the specific heat capacity of the copper calorimeter.

9 Compare your answer with that of some of your classmates. What do you find?

Explain your observations.

Transfer of heat

Heat naturally transfers from a body with a higher temperature to a body with a lower temperature. There are three actual mechanisms by which heat is transferred from one body to another:

- conduction
- convection
- radiation.

Conduction

If we use a metal spoon to stir hot porridge, we soon find that the handle of the spoon becomes hot. Heat from the stove is transferred to the cooking pot, which in turn transfers it to the porridge, the spoon and finally your hand. Heat is transferred through the metal pan and through the metal spoon. Heat travels through metals by **conduction.**

Heat transfers more readily through metals than through non-metals such as wood, glass and plastic. Metals are good conductors of heat because they contain free electrons, which are able to transfer heat energy. Wood, glass and plastic are poor conductors of heat (and of electricity). Poor conductors of heat are called **insulators.** Different metals conduct heat at different rates.

The rate at which a solid conducts heat depends on:

- the nature of the solid
- its cross-sectional area
- the temperature gradient between two points in the solid.

The best conductor of heat and electricity is silver, followed by copper. In the kitchen most cooking utensils have handles made of insulators such as wood, plastic or porcelain so that we can pick them up without getting our fingers burnt.

Insulators are of significant use in homes and industry, since they act as the safety part of tools and machine to prevent fire outbreak. Insulators help to control temperature.

ACTIVITY 3 Investigating the use of conductors and insulators in the home

1 Make a list of objects or devices in the home that have both a conductor and an insulator together.

2 Outline the function(s) of:
   a) the conductor
   b) the insulator.

3 Explain how temperature is controlled in the devices listed.

4 What provisions in a house:
   a) ensure a regular supply of heat
   b) regulate the temperature in the home?

Most liquids, except for a few such as mercury, are poor conductors of heat and electricity. Similarly most gases are poor conductors of heat and electricity.

For example, air is a poor conductor of heat. In temperate countries air is trapped between layers of glass in double-glazing to act as an insulator to prevent heat loss from rooms, especially in winter. In mountainous areas of Ghana such as Aburi, Amedzofe, Abetifi and Ashanti Mampong people wear sweaters and other thick clothing to insulate their bodies against heat loss.

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Convection

Convection is the transfer of heat energy by the circulation of a fluid as a result of the temperature differences within the fluid. When a fluid such as air is heated, it expands. The air particles gain kinetic energy and move more quickly. As air expands, its density decreases. Warm air is less dense than cool air and rises. Cooler, denser air moves in to take its place. The results of this are convection currents in which warm air rises and cool air falls. The same process occurs when any fluid is heated. In convection, the actual movement of the fluid itself transports heat, and it is always from a high temperature region to the lower temperature region. Convection will not occur in a fluid where there is thermal equilibrium.

Convection currents are involved at homes, offices and in industries for various purposes including:

- ventilation of rooms
- cooling of engines
- domestic hot water systems
- the functioning of refrigerators.

ACTIVITY 4 Investigating convection in liquids

1 Pour some clean water into a beaker.

2 Use a piece of glass tubing to direct a crystal of potassium permanganate to the corner at the bottom of the beaker (Figure 3.65). Gently remove the glass tube.

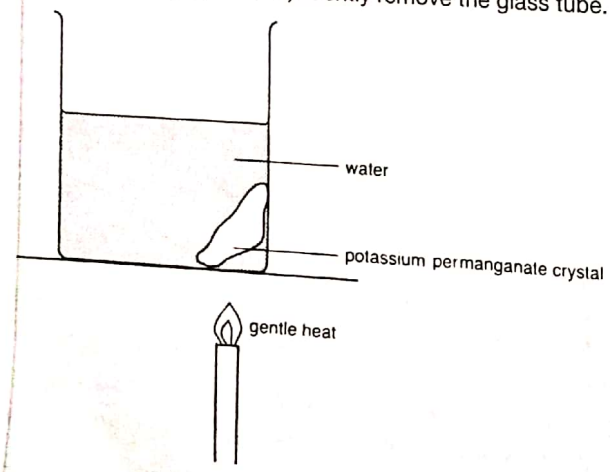


Fig 3.65 An experiment to show convection currents in water.

3 Gently heat the region where the crystal is located.

4 Draw a diagram of your observations. Use arrows to show the direction of the movement of the colours. What does the colour movement show? Give reasons for such a movement. List any three practical life situations in which such movement occurs.

Convection currents also play a role in some natural phenomena such as the formation of clouds and land and sea breezes.

When the air in a room is fresh and pure the room is said to be **ventilated**. At night, the temperature in the room becomes higher than the temperature outside. When the windows and doors are open, the lighter warm air inside the room is displaced by the denser cold air from outside. Through such convection currents, polluted air in the room is removed and replaced by fresh pure air. Carbon dioxide bacteria and excess moisture are sent out of the room in the process.

ACTIVITY 5 Investigating how convection helps in cooling engine systems

1 Visit a local auto mechanic (fitter's shop).

2 Let the mechanic help you to identify the parts of the cooling system of a vehicle engine.

3 Discuss with your teacher how the cooling system works.

4 Sketch the cooling system.

5 Compare your sketch with those of your classmates.

Radiation

ACTIVITY 6 Investigating radiation

1 Use a hand lens to focus the rays from the Sun on a sheet of dry paper or dry leaf.

2 What happens to the dry paper or leaf?

3 Explain your observation.

In Activity 6 the paper or leaf catches fire. This is because the Sun radiates heat energy. When this is focused on the paper or leaf it raises its temperature to ignition point. The energy from the Sun travels through space, which is a vacuum. Radiant energy travels in a form of electromagnetic wave; unlike conduction and convection, it does not require a material medium for its transmission.

A body transmits radiant energy when its temperature is higher than the temperature of its environment. Radiant energy travels in a straight line. It is observed only when the path of the energy is intercepted by a body. Black or dark surfaces absorb radiant energy faster and better than light-coloured or shiny surfaces. That

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is why black materials such as *brisi* or the black funeral cloth of the Akans of Ghana will dry faster and become warmer than a white material when exposed to radiant energy. Also, rough surfaces absorb radiant energy better than shiny surfaces.

Good absorbers of radiant energy are also good emitters of radiant energy. Shiny surfaces are poor emitters of radiant energy while black or rough surfaces are good emitters of radiant energy.

In some warm regions, such as Northern Ghana, most people wear white dresses, which are poor absorbers of radiant energy. Gas containers installed near kitchens at most Senior High Schools in Ghana are coated in shiny silver paint. Can you think of reasons why this is done?

The vacuum flask

Inside a vacuum (Thermos) flask (Figure 3.66) is a double-walled, silvered glass flask with a vacuum between the walls. This can be used to hold hot or cold items such as porridge, tea and ice cream. It is supported on two insulators (usually cork in most cases). It is closed with a cork or plastic stopper and encased in a metal or plastic container.

The cork support and cork stopper prevent heat loss or gain by conduction. The vacuum within the double wall of the flask also prevents heat loss or gain by conduction and convection.

Radiation of heat from the flask is prevented by the silver-coated surfaces of the walls of the flask, which reflect heat that would have passed out of, or into, the flask.

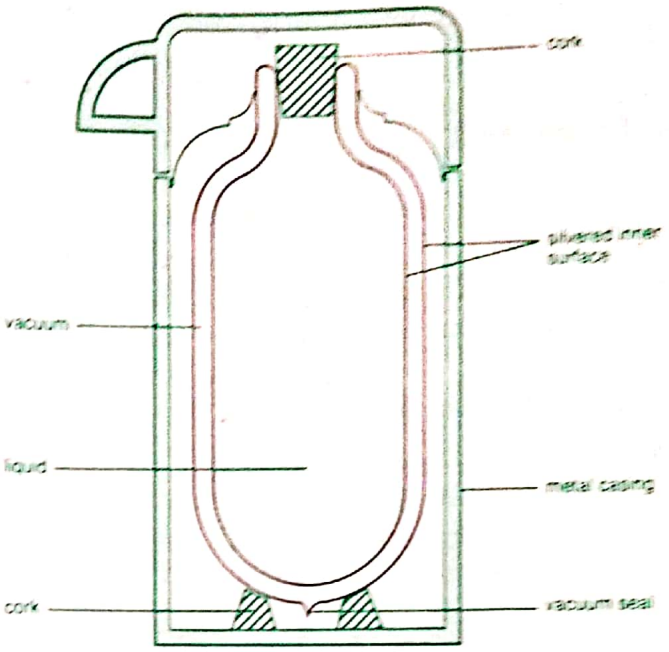


Fig 3.66 The vacuum flask.

Temperature

When a body gains energy, changes occur in the particles of which it is made. These changes can include a change in the colour of the body, in its shape, in its physical state, and in its temperature.

We measure temperature on arbitrary scales devised by scientists. Historically, the Fahrenheit scale was used but the Celsius scale and the absolute scale (based on the Celsius scale) have now replaced this. The units for these scales are degrees Fahrenheit (°F), degrees Celsius (°C) and the absolute temperature in kelvin (K). Notice that neither the symbol ° nor the word 'degree' is used in expressing absolute temperature.

On the Celsius scale, the lower fixed point is the temperature of pure ice melting (0°C), and the higher fixed point is the temperature of steam from pure water boiling under normal atmospheric pressure (100°C).The temperature of a substance is related to the kinetic energy of its particles: the higher the temperature, the greater the kinetic energy. The absolute scale of temperature is based on the kinetic theory of matter. It assumes that there must be a temperature at which the particles of a substance stop moving completely. No more energy can be removed from them: hence they are at the lowest temperature possible. This temperature is called **absolute zero**, and has the value –273.15°C or 0 K.

An interval of 1 K is exactly equal to an interval of 1°C; therefore temperatures in °C can be easily converted to temperature in K by adding 273.15 (or more commonly just 273). The symbol for absolute temperature is *T*.

The rate at which a temperature change occurs in a substance depends on the mass and the nature of the substance. When the same quantity of heat is applied to 100 cm^3 of water and 200 cm^3 of water in identical beakers the 100 cm^3 of water will attain a higher temperature over the same period of time. Objects with large masses take a longer time to warm up, as their internal energy is shared among a greater number of particles. Materials do not all respond to energy changes by the same amount. Given an equal quantity of energy, the particles in some materials will move faster than

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others, and hence there will be a greater increase in temperature.

Thermometers

Temperature is measured with an instrument called a thermometer. There are many kinds of thermometers; some work by the expansion of a liquid or gas when heated, while others depend on the expansion of a bimetallic strip. The types of thermometers that are used round the world include:

- liquid-in-glass thermometers
- gas thermometers
- bimetallic thermometers
- pyrometers
- thermocouples
- resistance thermometers
- digital and electronic thermometers.

Some thermometers measure temperatures more accurately than others do. Each has its own applications, uses and tolerances.

Liquid-in-glass thermometers

Most liquids expand when heated and contract when cooled. This fact is used in constructing liquid-in-glass thermometers. The liquid-in-glass thermometer (Figure 3.67) has:

- a bulb that serves as the reservoir of liquid
- a stem with fine uniform capillary glass tubing through which the liquid rises when the temperature increases and falls when the temperature decreases
- calibrations on the stem to read the temperature scale of the thermometer.

An increase in temperature causes an expansion and a corresponding increase in volume of the liquid in the bulb until the liquid reaches thermal equilibrium with its surroundings. Narrow capillary tube is used as the stem of the thermometer to ensure that any increase in the volume of the liquid in the bulb causes a significant (and hence easily seen) increase in the length of the thread in the stem.

A reliable thermometric liquid has the following qualities:

- The temperature range within which it remains a liquid is large.



Fig 3.67 Liquid-in-glass thermometer.

- It expands regularly and evenly with a rise in temperature.
- It does not cling to the walls of the glass tubing.
- It does not vaporise or condense in the tubing.

Liquids that satisfy these conditions include ethanol (ethyl alcohol) and mercury.

Ethanol freezes at –112°C and boils at 78°C. It is a good thermometric liquid for measuring room temperatures, human body temperatures, or the temperature of cold storage or fridges, and for use in lower-temperature regions such as the temperate regions that experience cold winters. The alcohol used as a thermometric liquid is usually coloured to make it easier to see.

For some applications **mercury** is the preferred thermometric liquid. It has a freezing point of –39°C and a boiling point of 357°C. The higher boiling point of mercury is an advantage when measuring substances at high temperatures, such as boiling water. However, unlike alcohol, the lower freezing temperature of mercury makes it unsuitable for measuring low temperatures.

Mercury does not wet the sides of the capillary glass tubing through which it rises or falls. It is opaque and therefore easily seen when reading the temperature.

Liquid-in-glass thermometers are handy and usually used in laboratories and clinics. When using a liquid-in-glass thermometer you should take the following precautions to ensure accurate measurement:

- Stir the substance to achieve an even distribution of heat throughout.

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- Make sure that the bulb of the thermometer is fully immersed in the substance.
- Do not let the bulb touch the bottom or the sides of the heated container since this may be at a higher temperature than the substance itself.
- Hold the thermometer at the opposite end from the bulb to prevent your body heat from increasing the temperature of the thermometric fluid.
- Allow sufficient time for thermal equilibrium to be reached. This is when the liquid level stops moving.

The clinical thermometer

Clinical thermometers are liquid-in-glass thermometers that are used in clinics and hospitals to measure human body temperature. The clinical thermometer is a **maximum-reading thermometer**: that is, one on which the temperature does not fall after the maximum temperature has been recorded.

The clinical thermometer (Figure 3.68) has a thin and short stem calibration ranging from 35 to 43°C. Normal human body temperature is 37°C, so the clinical thermometer has enough calibration for the purpose for which it is made. The limited range in scale increases its sensitivity. It has a kink in its stem between the bulb and the first mark on the scale. When the clinical thermometer is placed in the patient's body for a short time the body temperature causes the mercury in the bulb to expand along the tube. When the thermometer is removed from the body, the kink in the tube prevents the mercury from flowing back into the bulb. The mercury thread remains in the stem to indicate the patient's temperature. The liquid can be forced to flow back into the bulb by shaking the thermometer vigorously.

It is useful to sterilise a clinical thermometer before it is used again by immersing it in antiseptic solution or cleaning it with methylated spirit. This helps to prevent germs from spreading from one patient to others. Sterilising clinical thermometers in boiling water (100°C) will break the bulb.

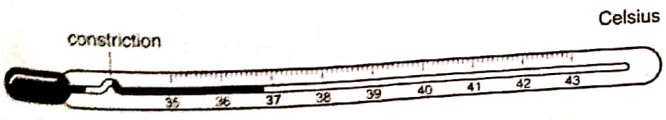


Fig 3.68 Clinical thermometer.

ACTIVITY 7 Investigating body temperature among students

1 Measure the body temperature of 10 girls and 10 boys in the class. Remember to sterilise the clinical thermometer each time it is used.
2 Record the results in a table.
3 Plot a histogram of the records obtained.
4 Repeat the activity four days later and plot a histogram of the records obtained.
5 Analyse the records to find out whether:
   a) the temperature varies from day to day in a particular student
   b) the temperature varies from one student to another at a particular time.
6 Give reasons for the answers obtained.
   a) Show situations in life that may lead to changes in body temperature.
   b) Suggest how the changes in (a) may be controlled.

Other types of thermometers

The **gas thermometer** (Figure 3.69) consists of a glass bulb containing dry air connected to a mercury manometer. When heat is applied to the bulb the dry air expands and exerts pressure on the mercury, causing the level of mercury in the open tube to rise. The difference in height between the two mercury levels is then measured to provide a pressure reading for the gas.

In industries such as Wahome steel works, and Aluminium Works Ltd in Tema, thermocouples, made from metals of high melting points, are used to measure the temperature of molten iron and aluminium respectively. In factories where metals such as aluminium and iron are melted, **thermocouples**, also called **thermoelectric thermometers**, are used to read the temperature. We can make a thermocouple in the

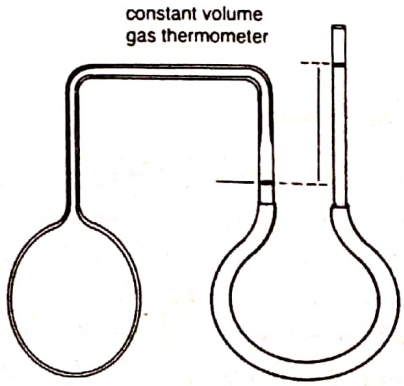


Fig 3.69 Gas thermometer.

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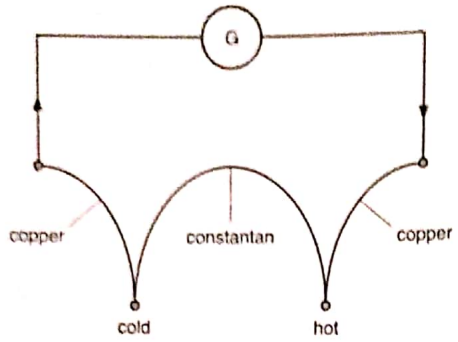


Fig 3.70 A thermocouple circuit.

science laboratory by joining two copper wires and a constantan wire together (Figure 3.70). The other ends of the copper wires are connected to a galvanometer, an instrument for measuring small electric currents.

One junction is inserted into melting ice and the other is immersed in the hot substance. An electromotive force is generated between the junctions, and this causes an electric current flow through the galvanometer.

Since the size of the current depends on the temperature of the hot substance, the galvanometer can be calibrated to read its temperature.

The colour emitted by a hot body varies with temperature and can be used to tell how hot the body is. This effect is used in optical **pyrometers**. In a pyrometer a current is passed through a filament of resistance wire placed inside a telescope to allow for the viewing of the inside of a furnace at the same time as the wire. The wire is heated by increasing the flow of current through it until its colour is similar to that of the furnace. At this point the current flowing through the wire can be related to a temperature by pre-calibration. The pyrometer can be used to measure temperatures up to about 3000°C.

Expansion due to heat

In general, when an object is heated it expands; it gets bigger. This occurs because the particles in the object move more vigorously when they are heated, and in doing so push each other a little further apart. Conversely, when cooled it contracts: it gets smaller. A mercury-in-glass thermometer clearly demonstrates the expansion effect that heating has on a volume of mercury.

The next activity is a simple experiment with a ball and ring apparatus that is often used to show that objects expand when heated.

ACTIVITY 8 Demonstrating that heating causes expansion

1 Pass a ball through a ring and record the observations.
2 Heat the ball over a heat source for some time and try to pass the ball through the ring again. What happens? Explain your answer.
3 Half fill a test tube with cooking oil. Mark the level of the oil on the glass.
4 Warm the oil gently over a suitable source of heat. What happens to the level of the oil in the test tube? Explain your observation using the concept of molecular kinetic energy.

Practical effects of thermal expansion

When objects are heated a change occurs in their molecular kinetic energy. This results in a powerful force that is evident in such things as cracks in road slabs, 'creeping' in railway lines, and sagging of telephone and electric cables, especially in the hot afternoon.

Expansion joints are provided between railway lines as in Figure 3.71(a), or creeping is prevented by providing overlapping joints (Figure 3.71(b)).

In some buildings expansion gaps provide room for expansion during warm seasons. Metal roofing sheets have their ends placed one on top of the other to allow for expansion. The cracking noise heard from roofing sheets of houses in the hot afternoons is due to expansion. Gaps are left between slabs in terrazzo works as well as between the building blocks. These gaps are usually filled with materials such as plastic to allow for expansion.

Thermal expansion is put to practical use to, for example:

- construct bimetallic thermostats for household electrical appliances
- build bimetallic thermometers
- remove very tight metal lids of bottles and jars
- rivet steel plates together in shipbuilding and in the construction of boilers.

The bimetallic strip

The bimetallic strip is made up of two different metals

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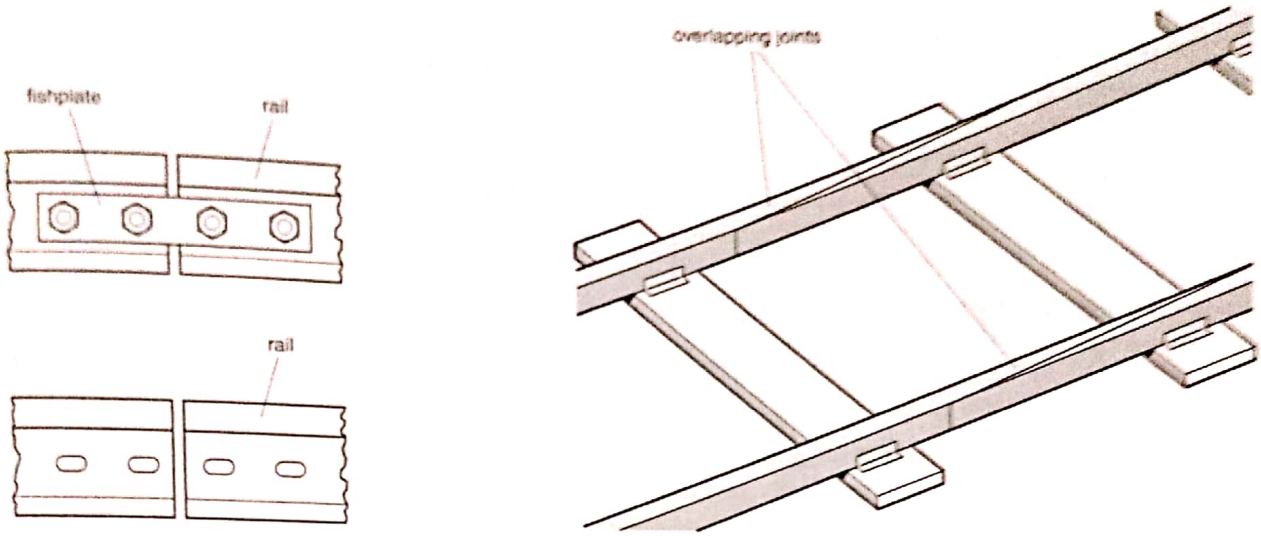


Fig 3.71 (a) Expansion joint and (b) overlapping joint in railway line.

such as brass and iron of the same length riveted together over their entire length (Figure 3.72). Brass expands more than iron for a given temperature increase, so when a bimetallic strip made of brass and iron is heated, it curves towards the iron. The brass is on the outside of the curve. The strip becomes straight again at room temperature. However, if its temperature is decreased below room temperature the brass contracts more than the iron, resulting in a curve towards the brass.

A bimetallic strip made of brass and invar (an alloy of steel and nickel) is thermally sensitive, and responds to the slightest changes in temperature. An increase of between 5 and 10°C causes the invar-brass bimetallic strip to curve. It is therefore used in the construction of **thermostats** and oven thermometers.

A thermostat is a device that controls or regulates temperature changes in devices such as gas cookers, deep freezers and electric irons. For example, as a bimetallic strip becomes hot and curves it may cut off the heating circuit in an electric iron at a particular temperature. Similarly, a thermostat can switch off the current to air conditioners or deep freezers.

In the **bimetallic thermometer**, invar and brass are riveted together to form a coiled bimetallic strip in the

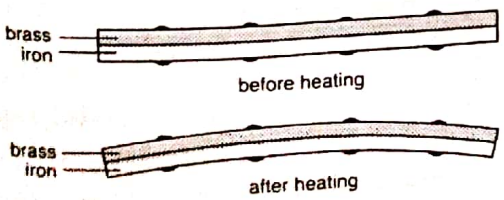


Fig 3.72 A bimetallic strip.

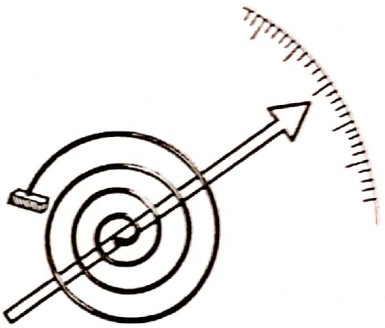


Fig 3.73 Bimetallic strip thermometer.

form of a spiral spring (Figure 3.73). The inside end of the spiral is attached to the spindle of a pointer; the outside of the spiral is fixed. An increase in temperature produces a greater expansion in the brass than in the invar. The difference in expansion causes the pointer to rotate over the calibrated dial in a clockwise direction to indicate the temperature.

Bimetallic strips are also used in electric flasher units (Figure 3.74), deep freezes, and automatic flasher units for advertisements. Car direction indicator lights (blinkers) also have bimetallic strips that control the lighting system of the unit.

The gas cooker thermostat

Gas ovens, used for baking, have a thermostat that regulates the gas supply to control the temperature (Figure 3.75). It consists of a brass tube fixed inside the oven. Inside the brass tube, and attached to the end of it, is an invar rod. Attached to the other end of the invar rod is a valve that controls the flow of gas from the gas supply

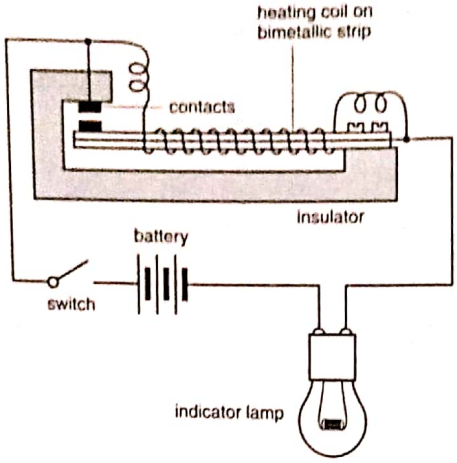


Fig 3.74 Electric flasher unit.

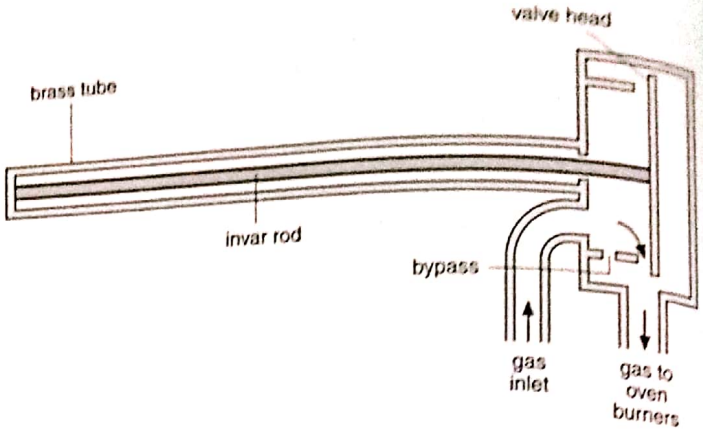


Fig 3.75 Gas oven thermostat.

to the burners. As the temperature increases the brass tube expands, drawing the invar rod with it, partially closing the valve. This reduces the amount of gas burnt, preventing the oven from getting hotter. A decrease in temperature causes the brass tube to contract, pushing the valve open more. This increases the flow of gas to the burners and the oven temperature increases. The temperature is controlled by adjusting the temperature control knob that is connected to the valve.

Expansion and contraction of liquids

Liquids take the shape of their containers. Such containers can expand with temperature increase. This makes it difficult to study the expansion of liquids. The expansion of the container depends on the type of material that it is made of.

ACTIVITY 9 Finding out about the expansion of a liquid

1 Fill a conical flask to the brim with a coloured liquid.
2 Insert a glass tube in a bung and fit the bung in the mouth of the flask so that one end of the tube enters the liquid and the other projects out at the top of the flask.
3 Mark the initial level of the liquid in the tubing.
4 Carefully insert the conical flask into a warm water bath, heat it and observe what happens to the marked water level. What do you observe? Explain your observation.

Careful observation will show that, on gentle heating, the level of the coloured liquid first falls; it then starts to rise, and continues to rise steadily in the tube until it overflows. On cooling, the liquid falls to its original level.

The initial fall in the level of the liquid shows that the container was expanding. The subsequent rise in the level of the water shows that the liquid was expanding faster than the expansion of the container. Cooling causes the liquid to contract and fall in level.

ACTIVITY 10 Investigating expansion in different liquids

1 Take five small conical flasks. Fill each with one of the following liquids: water, palm oil, frytol, glycerine and ethanol.
2 Fit a glass tube and bung to each as in Activity 9.
3 Mark the initial levels.
4 Arrange the flasks in a water trough and pour warm water at 75°C around them.
5 Stir the warm water thoroughly, mark and record what happens to the levels of the liquids in the tubing. Explain your observation.
6 Measure the height of the level above the rubber bung. Record and compare your observations.

Change of state of matter

Matter exists in three physical states: **solid**, **liquid** and **gas**. The state in which a type of matter exists depends on the temperature and pressure. Changes of state are easily understood if we consider matter to be made up

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of small particles and in turn changes of state provide evidence to support the particle theory of matter.

When the temperature of any matter increases, its molecules gain molecular kinetic energy, which sets the molecules in motion. The intermolecular distance increases.

When a **solid** is heated its particles vibrate more and more vigorously until they have sufficient energy to overcome the forces that hold them together. The solid melts into a **liquid** state. In the liquid state, the particles are able to move about but are still held loosely together. A further rise in temperature increases the kinetic energy of the particles until the bonds between them are totally broken. The liquid changes state into a **gas**.

These reactions are reversible. The gas can be condensed back into liquid by decreasing its molecular kinetic energy (cooling). Further cooling freezes the liquid back into a solid.

Melting

The particles of a solid are packed closely together (Figure 3.76). They are held together by strong forces of attraction. The particles are unable to move position but they are able to vibrate about their fixed positions. Their inter-particle distances are very small.

On heating, the particles vibrate more vigorously as the temperature of the solid rises. The vibrations become so violent that the particles partially overcome the forces of attraction which hold them in position and can move about. They are still attracted to each other but the distance between particles increases slightly. The heat energy supplied is used to overcome the attractive forces and therefore increase the distances between particles. There is a small increase in volume due to the slight increase in inter-particle distances.

The temperature at which a solid melts into a liquid is called the **melting point** of the solid. The temperature does not change during melting.

Substances have different melting points and boiling points (see Table 3.16). The melting point is also called the **fusion temperature** or the **freezing temperature**. The melting point of a pure substance can be used to identify it. Water changes from liquid to ice at temperatures between −4°C and 0°C. At the fusion temperature the molecules move closer and fuse or freeze

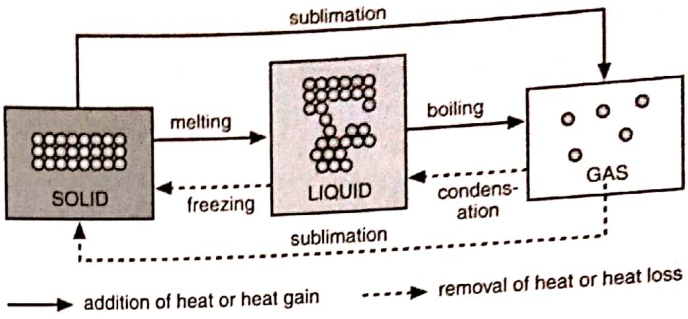


Fig 3.76 Changes between states of matter.

together into a new state which is solid. The loss of heat at the freezing temperature which does not physically indicate a change in temperature is referred to as **latent heat of fusion**.

Table 3.16 Melting points and boiling points of various pure substances

Substance	Melting temperature/°C	Boiling temperature/°C
water	0	100
ethanol	−114	78
nitrogen	−210	−196
oxygen	−219	−183
hydrogen	−259	−253
aluminium	660	2400
copper	1083	2380
iron	1539	2900

Note that it is the solid that melts *not* the individual particles.

Evaporation

At any particular temperature, the particles in a liquid are moving about and colliding with each other. However, not all particles travel with exactly the same speed; some move quickly while others move more slowly. Occasionally, a particle gains sufficient energy to break free and escape from the liquid surface. Escaping particles take a lot of heat energy with them. Evaporation therefore leads to cooling and to the disappearance of a liquid.

The rate of evaporation increases with increase in temperature. It also increases when inter-particle forces are weak, a large surface area of liquid is exposed to the atmosphere and it is windy. Drying washed clothes and evaporation of seawater to produce salt are two everyday examples of this change of state.

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Evaporation is the process by which individual particles escape from the surface of a liquid. The *rate* of evaporation depends on the nature of the liquid, the temperature of the liquid, the surface area of the liquid and the wind speed.

Boiling

The particles of a liquid are still close together although they are free to move about. When a liquid is heated the particles move about more and more energetically. Eventually, at the boiling point of the liquid, the particles have sufficient energy to overcome the forces of attraction that hold them together and the liquid becomes a gas. This takes place *throughout* the liquid and not just at the surface. During boiling there is no further rise in temperature. All the heat energy supplied at this point is used to separate the particles from each other. A large increase in the inter-particle distances occurs when a liquid boils (Figure 3.83) and becomes a gas; particles are further apart in gases than in liquids and solids.

The **boiling point** is the temperature at which a liquid changes into a gas. The temperature of a liquid remains the same once boiling has started.

ACTIVITY 11 Observing the effects of heating and cooling on some substances

Caution: Iodine and copper salts are toxic.

1 Cut a few pieces of paraffin wax from a candle. Heat them gently in a crucible or on a tin lid, using a pair of tongs. What happens during the heating?

2 Stop heating and allow the wax to cool. What happens?

3 Repeat the activity with the following substances: sand, ice block, solid fat and naphthalene. What do you observe?

4 Using test tubes and test-tube holders, heat and cool each of the following substances: crystals of iodine, ammonium chloride and copper(II) tetraoxo-sulphate(VI).

5 Using a pair of tongs burn a piece of magnesium ribbon in a Bunsen burner flame.

6 Record all your results in a table under the following headings 'Substance', 'Appearance before heating', 'Appearance during heating' and 'Appearance on cooling'.

ACTIVITY 12 Investigating states of matter

1 Place an ice cube in a boiling tube and hold the tube with a pair of long tongs. Heat the tube and the ice. What do you observe?

2 While heating, hold a clean glass plate over the top of the tube and record what happens. Explain your observation.

This experiment shows the three states of matter. The ice is the solid state, the water is the liquid state, and the vapour that condenses on the glass plate is the gaseous state. Figure 3.77 shows a cycle of the states of water.

When a liquid is heated it warms up until the **boiling point** is reached. The boiling point of a pure substance occurs at a specific temperature. The boiling point of substances changes with:

- the purity of the substance
- atmospheric pressure.

Evaporation is a process by which a liquid changes into vapour. It occurs at all temperatures. A liquid evaporates because molecules escape from its surface. If the rate at which molecules escape increases to the point where the **vapour pressure** above the liquid is equal to the atmospheric pressure, the liquid boils.

Evaporation of a liquid increases with:

- increase in temperature
- decrease in the density of the liquid
- decrease in atmospheric pressure
- increase in the exposed surface area
- speed of wind.

During the process of evaporation, the faster-moving liquid molecules have enough energy to escape. As they

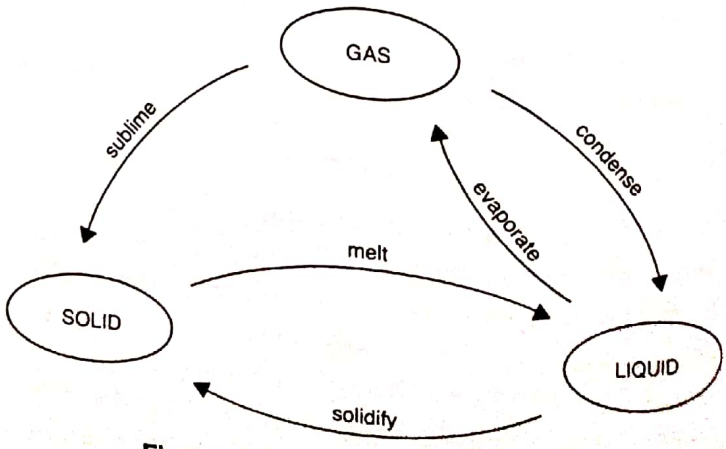


Fig 3.77 Changes of state of water.

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leave, the average speed of the remaining molecules drops, causing a fall in temperature for the liquid that is left. This cooling effect of evaporation is used by our bodies when we sweat through our skin. The sweat evaporates and so helps to keep us cool.

In the gaseous state, the molecules of the substance are free to take up any shape. The kinetic energy of the molecules in a gas is higher than that of the molecules in a liquid. A cooking pot is often covered to retain vapour inside the pot, in order to increase the vapour pressure and so prevent further evaporation and speed up the rate of cooking. Steam is very hot, and can be harmful when it touches the skin.

When a gas is cooled, **condensation** occurs. The gas changes state to become liquid. Further cooling turns the liquid into solid.

ACTIVITY 13 Cooling and refrigeration

Caution: Iodine and copper salts are toxic.

1 *Work in groups* to discuss what happens to water in a clay pot once it has been left standing for some time.

2 Discuss the process by which food that is refrigerated is cooled down. Why is refrigeration important?

Latent heat

When water at room temperature is heated, its temperature rises steadily until it reaches the boiling point of 100°C. The heat has changed the temperature of the water without changing its state. At 100°C the water continues to receive heat energy, but the temperature now remains constant. At this stage bubbles of water vapour form in the body of the liquid, rise to the surface of the water, burst and escape as steam. The quantity of heat energy released or absorbed when a substance changes its physical state at constant temperature is called the **latent heat** (symbol L).

A large amount of energy is needed to separate the molecules of a liquid and set them free. This accounts for the extreme hotness of the vapour of most liquids. By careful experiment, it is found that 2.26 MJ of heat energy is required to convert 1 kg of water into water vapour at the same temperature. This amount of concealed or hidden energy that goes into the vapour is called the **latent heat of vaporisation.**

The **specific latent heat of vaporisation** of a substance is the quantity of heat required to change 1 kg of the substance from the liquid state to the vapour state without a change in temperature. The same quantity of heat is released during condensation. The symbol for the specific latent heat of vaporisation is L, and the SI unit is joules per kilogram, J kg^{-1}. Different substances in their pure state have different specific latent heats of vaporisation (Table 3.17).

Table 3.17 Latent heat of vaporisation of some liquids

Substance	Latent heat of vaporisation/J kg^{-1}
ethanol	863 000
chloroform	243 000
ether	347 000
turpentine	293 000
water	2 260 000

When ice is melting into water, extra heat energy is required to weaken the bonding between the molecules. The heat required to change the physical state of ice, turning it into water, is called the latent heat of fusion.

The specific latent heat of fusion of a substance is the quantity of heat needed to change a mass of 1 kg of the substance from solid into liquid without a change in temperature. Different substances have different values of specific **latent heat of fusion** (Table 3.18).

Table 3.18 Latent heat of fusion of some liquids

Substance	Latent heat of fusion/J kg^{-1}
aluminium	384 000
copper	167 000
gold	66 500
ice	334 000
lead	20 900
naphthalene	164 000
paraffin	14 000

For calculation purposes in general:

Heat supplied or removed = specific latent heat × mass of material changing state

$Q = L \times \Delta m$

Worked example 3

How much heat is required to vaporise 100 g of water at its normal boiling point? The specific latent heat of vaporisation of water is 2.26 MJ kg^{-1}.

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Solution

$$Q = L \times \Delta m$$
$$Q = 2.26 \times 0.1$$
$$Q = 0.226 \text{ MJ or } 2.26 \times 10^5 \text{ J}$$

Worked example 4

How much heat is needed to melt 100 g of ice at 0°C? The specific latent heat of fusion of water is 336 kJ kg^{-1}.

Solution

$$Q = L \times \Delta m$$
$$Q = 336 \times 0.1$$
$$Q = 33.6 \text{ MJ or } 3.36 \times 10^4 \text{ J}$$

Sublimation

Substances such as solid iodine, camphor and sodium chloride can change from solid into gaseous state without becoming liquid. Such substances is sublime. **Sublimation** is the process by which a solid changes directly into a gaseous state and vice versa.

Self check

For questions 1 to 17, choose the letter that refers to the correct option.

1 The degree of hotness of a body is referred to as its
- A heat capacity
- B temperature
- C internal energy
- D melting point

2 373 K is equivalent to
- A 50°C
- B 70°C
- C 100°C
- D 103°C

3 Heat is transferred along an iron rod by
- A conduction
- B radiation
- C convection
- D reflection

4 A change of state directly from solid to gas is called
- A condensation
- B fusion
- C sublimation
- D vaporisation

5 A thermometer is used to measure the
- A heat capacity of a body
- B latent heat capacity of a body
- C specific heat capacity of a body
- D temperature of a body

6 The heat required to raise the temperature of 5.0 kg of water by 5°C (specific heat capacity of water is 4200 J kg^{-1} K^{-1}) is
- A 50.0 kJ
- B 85.0 kJ
- C 105.0 kJ
- D 115.0 kJ

7 Heat is lost through the skin by all of the following processes except
- A condensation
- B radiation
- C conduction
- D evaporation

8 The heat required to melt a substance (melting point 60°C, specific heat capacity 100 J kg^{-1} K^{-1} and latent heat of fusion 20 000 J kg^{-1}) of mass 0.50 kg, initially at 50°C, is
- A 1050 J
- B 1500 J
- C 10 000 J
- D 10 500 J

9 Which of the following statements about the absolute scale of temperature is correct?
- A The temperature scale starts at 273 K
- B The zero point is 273 degrees below 0°C
- C The temperature at which ice melts is –273 K
- D The temperature at which water boils is 100 K

10 A piece of ice is trapped at the bottom of a test tube full of water, and the test tube is heated near the top. The ice remains unmelted even when the water at the top of the test tube boils. Which of the following is not a factor that prevents heat reaching the bottom of the tube?
- A Water is a poor conductor of heat
- B Glass is a poor conductor of heat
- C There are no convection currents through the water
- D There is no downward radiation through the water

11 Which of the following statements are correct when a substance absorbs heat?
- I The quantity of heat in the substance increases
- II The molecules move faster
- III The volume of the substance changes

- A I and II only
- B I and III only
- C II and III only
- D I, II and III

12 Which of the following statements are true? In finding the boiling point of a liquid the bulb of the thermometer is placed in the vapour of the liquid and not in the liquid itself because
- I different parts of the liquid may be at different temperatures
- II dissolved impurities alter the boiling point of a liquid
- III the bulb of the thermometer may crack.

- A I and II only
- B I and III only
- C I, II and III
- D II and III only

13 The purpose of the constriction in the stem of a clinical thermometer is to
- A prevent the liquid from expanding beyond that point
- B prevent the liquid from flowing back into the bulb
- C increase the flow of the liquid
- D make the thermometer respond more quickly to temperature change.

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14 Which of the following statements about evaporation is correct?
- **A** It only occurs at certain temperatures
- **B** The rate increases with a decrease in temperature
- **C** It occurs throughout a liquid
- **D** The faster moving particles escape from the surface of a liquid

15 Sunlight can raise the temperature of metals more quickly than raising the temperature of water because
- **A** the specific heat capacity of metal is lower than that of water
- **B** the specific heat capacity of metal is greater than that of water
- **C** metals radiate more heat than water
- **D** water conducts heat more quickly than metal

16 400 g of water at 30°C is mixed with 200 g of water at 80°C. Neglecting heat losses, what is the temperature of the resulting mixture?
- **A** 0.477°C
- **B** 4.77°C
- **C** 47.7°C
- **D** 477°C

17 Which of the following statements about mercury as a thermometric liquid is true?
- **A** It has a low heat capacity
- **B** It is colourless
- **C** It does not vaporise
- **D** It has a high density

18 **a)** Define the specific heat capacity of water.
b) Describe an experiment to find the specific heat capacity of water.

19 Describe the features by which heat loss in a Thermos flask is minimised.

20 **a)** State three reasons why mercury is suitable for use in a liquid-in-glass thermometer.
b) Under what conditions might alcohol be preferred to mercury in a thermometer?

21 **a)** Give details of an experiment to demonstrate that metals expand as they get hotter.
b) Explain the differences between evaporation and boiling.
c) With a suitably labelled graph, show how the temperature changes with time when an ice block at −10°C is heated until it becomes steam.

22 Give two examples where the expansion of a solid when heated is made use of, and two examples where expansion is a difficulty that has to be allowed for. In the latter examples, explain what allowance is made.

23 Explain the following statements:
a) A vacuum is the worst possible conductor of heat.
b) In hot sunny weather ice cream will take longer to melt if it is wrapped in newspaper.

24 The ice and steam points of a certain thermometer are found to be 15.0 cm apart. Calculate the temperature, in °C, when the length of the liquid thread in the thermometer reaches 9.0 cm above the ice point mark.

25 A bimetallic strip consists of equal 50 cm lengths of brass and iron at 25°C. Explain what will happen if the strip is heated to 100°C.

26 Describe, on the basis of atomic and molecular structure, how heat energy is conducted along an iron rod.

27 **a)** What evidence is there to suggest that the molecules in a gas are wider apart than in a liquid?
b) Explain the following in terms of changes of state and indicate the role of heat in each process:
(i) sublimation
(ii) melting
(iii) condensation
(iv) evaporation.

28 **a)** Define latent heat of fusion.
b) Distinguish between latent heat of fusion and latent heat of vaporisation.
c) Two solids, A and B, have heat capacities of 400 J K^{1} and 546 J K^{1} respectively. Explain this statement.

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3 Electronics

Learning objectives

After studying this unit you should be able to:

1 investigate the use of a transistor as a switch
2 describe the use of basic logic gates in contactless electronic switching.

Background information

Transistors act as switches to amplify signals. Transistors role in functioning of logic gates facilitate the functioning of computers, calculators and security electronic gadgets. Transistors have become an indispensable component of electronic gadgets.

Transistors

We discussed transistors at the Junior High School level and in the second year of our course. We found out that transistors serve as switches in electronic circuits.

The transistor as a switch

Transistors are used as current control switches. A relatively small current that flows through the base of the transistor can exert control over a much larger flow of electrons through the collector to amplify a signal. It can be used with other components to make switching in forward or reversed bias circuit.

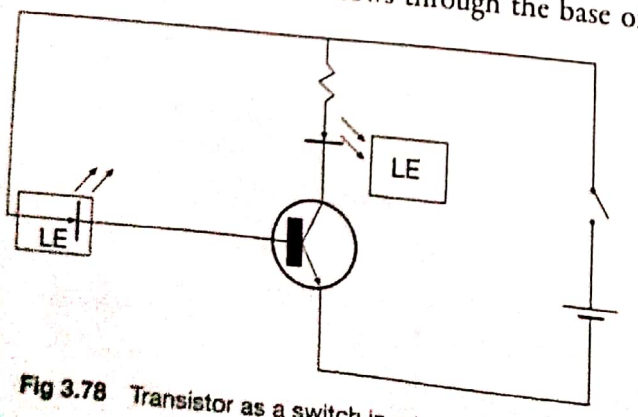


Fig 3.78 Transistor as a switch in a transistor circuit.

Project

Design and construct a remote control switch using a transistor. Indicate fields in which the product from your project could be applied.

Transistor circuits arranged as logic gates

Circuits in which transistors act as high-speed switches are referred to as **logic gates**. Logic gates are used in devices such as computers, electronic calculators, telecommunication and many digitised gadgets such as clocks and watches.

Logic gates have two inputs with two levels of voltage referred to as high or low. High implies closer to supply voltage and low means zero voltage or off. High is identified as logic gate level 1 and low as logic gate level 0. The output in such circuits depends solely on the input. In this circuit high or on means 1 and low or off means 0. The name of the gate corresponds to the inputs for the output to be on or off.

There are five common logic gates. These are simply referred to as gates. The logic gates are:

- NOT gate
- AND gate
- NAND gate
- OR gate
- NOR gate.

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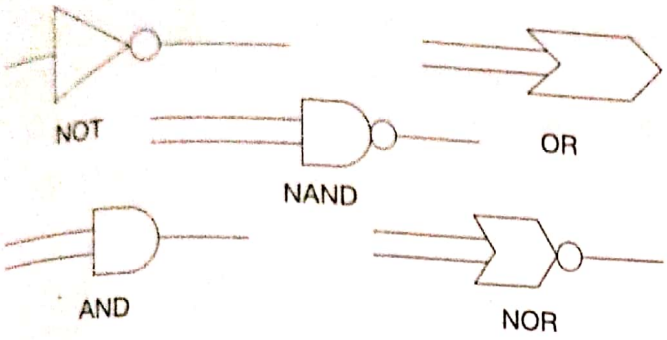


Fig 3.79 Logic gates symbols.

Their symbols are shown in Figure 3.79.

Note that NOR stands for NOT or that is not. This is followed by OR and NAND which is interpreted as AND followed by NOT.

NOT gate

NOT gate has only one input and one output. A lone transistor switch is responsible for the NOT gate and is shown in a circuit diagram as follows:

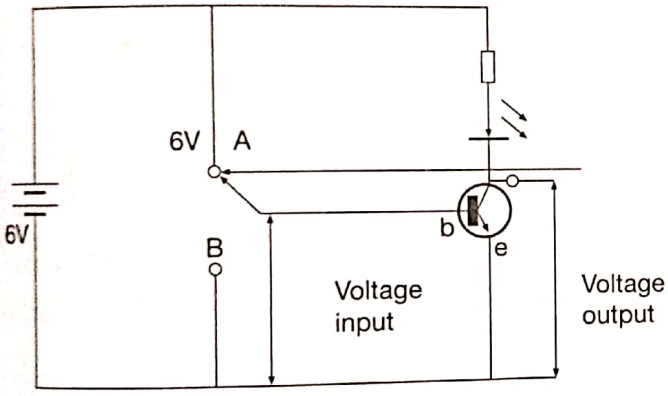


Fig 3.80 Circuit for NOR gate.

The NOT gate produces a light output if the input is low and higher output if the input is high. This implies that the output is high even if the input is NOT high.

In this circuit if the input voltage is connected to the 6 V terminal, voltage would be high and also causes the base current to flow and a large collector current flows through the resistor and the **light emitting diode** (LED). This sets up a high voltage across the resistor R close to the 6 V and a low voltage for the transistor.

When the input voltage is connected to the 0 V terminal, the voltage in the circuit becomes low. In such a situation no base current will be recorded and a smaller collector current registered. Thus the voltage across the resistor R will be small and the output voltage for the transistor will be high.

Table 3.19 NOT gate

Input	Output
0	1
1	0

OR gate

In an OR gate, a 1 output is registered if any of the inputs are 1s, the output is zero (0) if all the inputs are 0s. The figure which follows illustrates the OR gate.

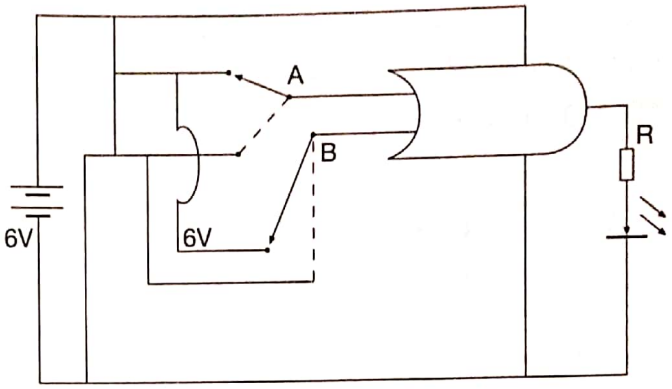


Fig 3.81 Circuit for OR gate.

ACTIVITY 1 Exploring an OR gate

Materials needed: OR gate switch, 6 V battery, double throw switch.

1 Connect the circuit as in figure 3.82 which follows.

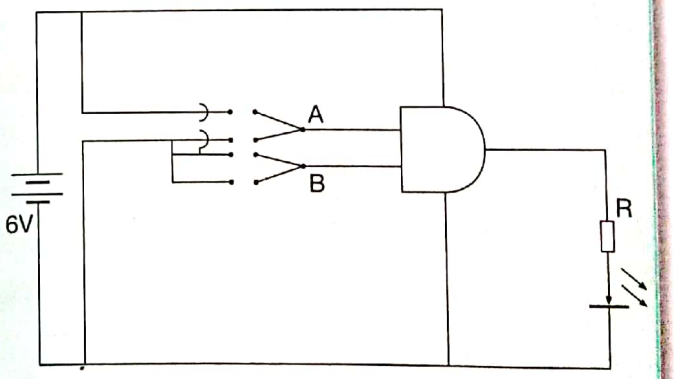


Fig 3.82

2 Switch on the input A to high and B to high.

3 Observe and describe the behaviour of the LED.

4 Switch with both on high and B on low and record the behaviour of the LED

In this activity the output of the OR is as tabulated in the following table

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Input		Output
A	B	Y (A.B)
0	0	0
1	0	1
0	1	1
1	1	1

The 0 stands for Low and 1 for High and Y = A and B.

AND logic gate

The AND gate produces an output of 1 only when the inputs are 1s. If any of the input are 0s the output is 0.

NAND logic gate

ACTIVITY 2 Exploring the NAND gate

Materials needed: NAND gate, double throw switch, double pole, LED.

1 Connect the NAND gate circuit

2 Record the behaviour of the LED with the inputs on
   (i) High
   (ii) Low
   (iii) Switches reversed

   What differences do you notice?

3 Design a table for your observation on the NAND gate. Draw your conclusions based on the tabulated data.

Your table should be as follows:

Input		Output
A	B	Y (A → B)
0	0	1
1	0	1
0	1	1
1	1	0

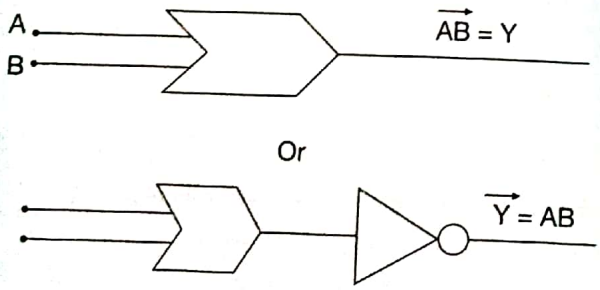


Fig 3.83

The NAND gate gives out an output 1 except when both inputs are 1s, in that case the output is 0.

NOR Gate

Do you still remember that the NOR gate is a combination of NOT and OR gate?

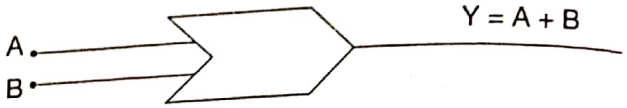


Fig 3.84

ACTIVITY 3 Investigating a NOR gate

Materials needed: NOR gate, test circuit on NOR.

1 Connect the NOR gate in the test circuit

2 Switch the inputs to high and low and interchange the throws by alternating the high and low.

3 Record your observation about the behaviour of the LED and tabulate the inputs and outputs.

Your truth table will be as in the table which follows.

Input		Output
A	B	Y A B
0	0	1
1	0	0
0	1	0
1	1	0

The NOR gate is the gate that the inputs produces low or on 0 or 1.

PROJECT

Work in groups to design and construct a simple circuit that produces flashing light using your knowledge about gates.

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Self check

For questions 1 to 5, choose the letter that refers to the correct option.

1 Which logic gate will produce the following table as an output for the inputs

Input		Output
A	B	
0	0	0
1	0	1
0	1	1
1	1	1

A NAND
B OR
C NOR
D NOT

2 Logic gates are

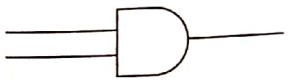
A computer programmes for learning
B circuits in which transistors act as high-speed switches
C High-speed calculators
D Digitised gadgets such as clocks

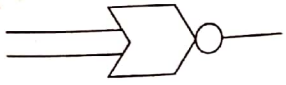
3 The input and output as found in the following table is associated with which of the following logic gates

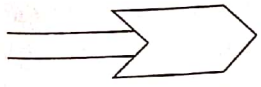
Input	Output
0	1
1	0

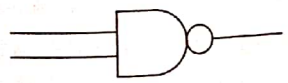
A NOR
B NAND
C NOT
D AND

4 Select the best symbol for NAND logic gate.

A 

B 

C 

D 

5 Which of the logic gates produces the following output?

Input		Output Y (A→B)
A	B	
0	0	1
1	0	1
0	1	1
1	1	0

A NAND
B AND
C NOR
D OR

6 Compare the outputs of NAND and NOR logic gates and interpret the data. Give two examples of gadgets in which each is applied.

7 What type of switch is used in a circuit for NOR logic gate? Give reasons why your chosen switch is preferred.

8 Design an experiment to explore the OR logic gate and design a table for its output.

9 Draw a transistor controlled logic gate circuit that produces flashing light. Show the components of the circuit and give two examples of the application of flashing light.

10 What is the role of transistors in logic gate circuits?

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1 Variation, inheritance and evolution

Learning objectives

After studying this unit, you should be able to:

1 relate the nucleus, chromosomes and genes as a sequence in inheritance
2 explain with examples the causes and consequences of variation
3 explain the concept of inheritance in organisms
4 explain how sex is determined in humans
5 discuss the inheritance of the various blood groups and Rh factor and outline their importance
6 explain how a sickle cell gene is inherited and sickle cell anaemia is acquired
7 explain evolution and discuss some theories of evolution
8 cite some evidence for evolution.

Background information

In nature, it is scientifically established that every organism is unique. The variation of species and their function offer a wide spectrum of knowledge and skills for their management and uses for sustainable development.

The variations of matter find expression in all spheres of science and make an interesting field of study.

There are many hundreds of thousands of different species of plants and animals in the living world. Even within each species there can be variation in many characteristics, e.g. variation within the species *Homo sapiens* (humans).

Children usually resemble their biological parents. It is also true to say that tall parents usually have tall children and that black parents have black children. In 1865, an Austrian monk, Gregor Mendel, published the first laws of genetics. These were the result of experiments he conducted in crossbreeding varieties of garden peas.

Where did the millions of living things on this planet originally come from? This is an age-old question and many different theories have been put forward in an attempt to answer it. The two main arguments put forward are those of special creation and evolution.

Supporters of special creation believe that all living organisms were created by a divine being or God. Some believe that this creation happened when the Earth was created. Others believe it to have happened several times throughout the history of the world. It is assumed by creationists that living things have remained unchanged throughout history and are exactly as they were when they were first created.

Chromosomes and genes

A hybrid is the offspring resulting from cross-breeding different plants or animals. Most of the individual's characteristics result from the information acquired by the offspring through the gametes (sperm and eggs) from the parents. Each one of the gametes carries a haploid number of chromosomes.

A chromosome is a filamentous body found in the nucleus of a cell. A fully structured chromosome consists of two halves called chromatids (Figure 3.86). The centromere is the point which joins the chromatids. Each chromosome is made up of numerous genes. The hereditary characteristics of the individuals are imprinted on the genes.

The chemical nature of the gene has been found to be a nucleic acid called deoxyribonucleic acid (DNA). The DNA is formed by molecular elements

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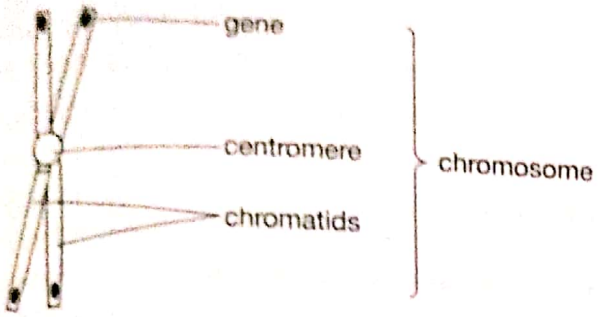


Fig 3.86 A chromosome.

called nucleotides which unite linearly making long chains. A gene is therefore a fragment of DNA while a chromosome is a sequence of DNA and therefore a sequence of genes.

The genome is the set of all the genes of the chromosomes. In the case of the human genome, it is made up of a sequence of 3000 to 3500 million (or 3.0 to 3.5 billion) units. In the genome are printed the biochemical instructions that rule the birth and development of each person, which is now known as the genetic code.

The nucleus of the cell is the central governing core where the chromosomes are located.

Hereditary laws

As we have seen earlier, the sex cells (gametes) carry haploid number of chromosomes within which genes are located. The somatic cell (i.e. the body cell) is the result of the two sets of haploid chromosomes, each set of which is a contribution from each parent. A pair of genes will therefore control a single trait, e.g. height, skin colour and so on. A pair of genes (two possible versions of a gene) controlling a single trait is called the allele.

Gregor Mendel was an Austrian monk who devoted his life to the study of inheritance of traits or characteristics. He worked on a garden pea plant and in 1866 he published 'Experiments in plant hybridization'. This formed the basis of genetic science. Gregor Mendel formulated three main laws known as Mendel's laws of inheritance. The first law is also known as the law of dominance, the second law is known as the law of segregation of genes and the third law is also known as the law of independent combination or independent assortment.

Mendel's first law

Mendel's first law states that the characteristics of an organism are controlled by genes occurring in pairs and of a pair of such genes only one can be carried in the gamete. The law is also known as the law of uniformity of hybrids of the first generation.

Variation

The term variation describes the differences in characteristics shown by organisms of the same species. Inherited factors determine the genetic make-up of an organism which becomes expressed in its structural and physiological characteristics. The extent to which these characteristics develop may be influenced by the environment.

Discontinuous variation

There are certain characteristics within a population which exhibit a limited form of variation. Thus individuals with this type of variation show clear cut differences, e.g. blood groups in humans, rats with black or brown coats, tall or dwarf pea plants and gender in humans and in other animals. These characteristics are controlled by one or two major genetic factors and are not affected by environmental conditions.

Continuous variation

Many characteristics in a population show complete gradation from one extreme to the other with intermediate forms between the two extremes. This type of variation is illustrated by weight, height, finger length, feet length, etc. in humans. These characteristics may be influenced by genetic factors and by environment, e.g. food supply.

ACTIVITY 1 Investigating variation in height in humans

1 Measure your height against a scale marked on a wall or using a tape measure.

2 Obtain the heights of as many members of the school as possible (all measurements should be made to the nearest cm).

3 Combine the heights into groups, recording the number of heights in each group, as in this example:

Height/cm	Number of pupils
120–129	5
130–139	11
140–149	35

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4 Plot a graph with height group on the horizontal axis and number of children on the vertical axis.

5 Your graph should be in the shape of a curve. Describe the curve. A bell-shaped curve shows that the variation is continuous.

6 Compare this with the graph in Figure 3.87. This illustrates discontinuous variation in pea plants which are either tall or dwarf.

7 Carry out a similar investigation into the variation in weight of pupils in the school.

8 What is the main difference between continuous and discontinuous variation?

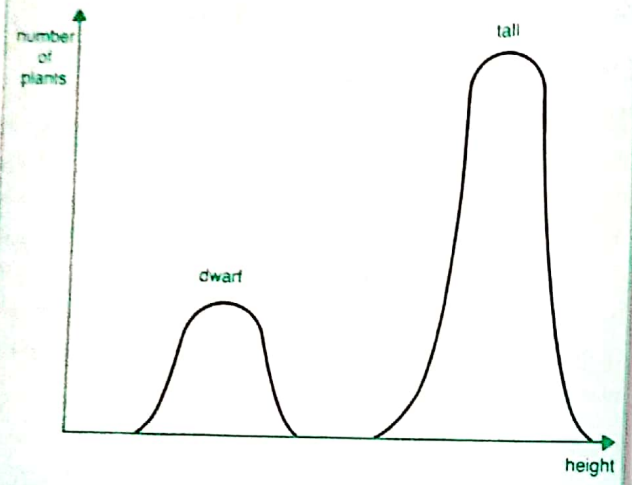


Fig 3.87 Height in pea plants.

ACTIVITY 2 Investigating variation in maize

1 Find out from different kinds of maize how they differ from each other. Look for differences in size, shape and colour of kernels.

2 Discuss your findings in class.

Causes of variation

Some characteristics are inherited. Others are acquired as a result of environmental influences. Examples of inherited characteristics include blood groups, skin colour, eye colour, baldness and albinism. Examples of variations due to environmental factors are scars, knowledge and language.

Environmental factors

Environmental factors are external conditions that affect or influence the life processes and cause differences among living things belonging to the same species. Variations caused by environmental factors are not inherited. Some environmental factors which cause variations are described below:

- **Diet** – a balanced diet is necessary for normal growth and development. When the diet is lacking in some way, deficiency diseases can occur, e.g. kwashiorkor, marasmus or rickets. A person who inherits genes for tallness has the potential to grow tall but if malnourished, may not reach his or her full potential height.
- **Light intensity** – plants growing in bright light tend to have smaller leaves than those of the same species growing in the shade.
- **Wind velocity** – plants growing in windy areas may develop stronger root systems than those of the same species growing in areas where wind velocity is low. Trees and shrubs, growing where there is a prevailing wind, adopt a growth habit which slopes away from the force of the wind.
- **Other organisms** – disease-causing organisms cause various diseases in other organisms which sometimes leave permanent features (scars and internal damage), making individuals different from the rest of the population. For example, river blindness makes its victims look different from the rest of the population.
- **Altitude** – the amount of oxygen in air decreases with increase in altitude. People who live on higher ground therefore have more red blood cells per cubic centimetre in their blood than those who live on lower ground. In Africa, for example, Kenyans have more red blood cells per cubic centimetre in their blood than Ghanaians.

Genetic factors

Genetic factors are those which are connected with heredity. Variation in this case is caused by the behaviour of chromosomes at meiosis (see Year 1, Section 1, Unit 5) and the interaction of genes. Genetic factors which cause variation include:

- segregation and recombination
- independent assortment
- polygenic characters
- co-dominance (partial or incomplete dominance)
- mutation.

The first four are to do with normal inheritance and will be discussed in the next section.

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Mutation

Mutation is the sudden change in the genotype (genetic make-up) of a cell. If the cell is a gamete or zygote, the whole offspring will be affected and the mutation is hereditary. If the cell is an ordinary somatic cell (non-reproductive), only part of the organism is affected. Moles on the skin are caused by mutation of the gene controlling pigment colour in skin cells. The mutation is passed on by mitosis, forming a patch of abnormal coloured cells called a mole.

Mutation may be spontaneous, that is, it may occur naturally. It can also be induced by artificial means using mutagens. Mutagens, also called mutagenic agents, are influences, including environmental influences, that cause mutation. Mutagenic agents include X-rays, gamma rays, ultra-violet rays, cosmic rays and some chemicals such as benzene and mustard gas.

The rate of natural mutation is very low – one to thirty per million in gametes – and the mutation frequency is one in 500 000 individuals. Mutations may be disadvantageous or advantageous. Advantageous mutations are rather rare. Both chromosomes and genes may undergo mutation.

Chromosome mutation involves various changes in the structure of chromosomes. For example, a chromosome may break in two places and then rejoin, leaving the middle bit out. This results in the loss of several genes and is usually lethal. Alternatively, part of a chromosome may break off and attach to another non-homologous chromosome. This alteration in the sequence of genes may produce a beneficial variation.

Another type of chromosome mutation is the addition or loss of one or more complete chromosomes. Down's syndrome (resulting in mental retardation and reduced resistance to infection in humans) is caused by an extra chromosome in the cells.

Polyploidy is a condition where an organism acquires one or more complete, extra sets of chromosomes. This is rare in animals, but quite common in plants, often producing new species with beneficial characteristics.

Gene mutations are caused by changes in individual genes. Alteration of the sequence of nucleotides of the DNA which corresponds to a single gene causes changes in the order of amino acids in the protein formed. An example is Haemoglobin S, produced by a change in two nucleotides in the DNA for the formation of haemoglobin. Gene mutation may result in the abnormal functioning of a vital protein, causing early death. In this case the gene is referred to as a lethal gene.

Consequences of variation

Natural selection

Genetic variation plays an important part in natural selection. This phenomenon enables certain organisms to survive whilst others are less successful. The mechanism of natural selection is as follows:

- there are variations within every species
- some of these variations are hereditary (genetic)
- some variations are favourable while others are not
- favourable variations give some selective advantage over unfavourable variations
- in all species, some organisms die before reaching sexual maturity
- individuals with unfavourable variations are more likely to be eliminated by earlier death than others
- there are natural agents (e.g. climate, competition for food, reproductive capacity) which produce differential mortality that leads to a greater chance of survival of those with selective advantage
- individuals with selective advantage are more likely to survive and pass on their advantageous genetic variations to their offspring.

All of the above result in gradual changes in organisms, which enable them to cope with changing environmental conditions (see below).

Inheritance in organisms

Inheritance refers to the handing on of characteristics (characters or traits) of an individual called the parent to its offspring through reproduction. In sexual reproduction, an offspring is produced from two parents referred to as:

- father, or male parent
- mother, or female parent.

During sexual reproduction, the nucleus of the male gamete (spermatozoan) and the nucleus of the female gamete (egg or ovum) fuse together to form a zygote. Each sex cell carries a haploid number of chromosomes. Each and every cell of our organism has 46 chromosomes, which is the diploid number characteristic of human beings.

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Therefore when the two gametes, each having a haploid number of chromosomes, unite, this will make up a cell with a diploid number of 46 chromosomes, characteristic of the human species.

Characteristically, the offspring produced possess traits or features of both parents, the father and the mother. Hence, from its parents, an individual inherits the characteristics of the species.

This is the pattern of inheritance which is also seen in flowering plants during sexual reproduction.

Different species have different chromosomal numbers which remain constant from generation to generation.

Certain traits or characters, though inherited from parents, may not necessarily be handed over or passed on from parents to offspring. This is because the environment influences the characters.

These characters are referred to as non-heritable characters. Examples are:

- height
- skin colour
- hair colour
- body weight
- intelligence.

Characters which can be handed over or passed on from parents to offspring are called heritable characters. Examples are:

- blood groups inheritance
- rhesus (Rh) factor
- haemoglobin genotypes
- colour blindness
- tongue rolling.

Heredity is the passing on of the traits or characteristics of parents to their offspring. The branch of science that deals with this process is called genetics.

The cell contains a nucleus which carries all the information concerned with heredity. This information is carried on strands of a material called **DNA** which cannot normally be seen. However, when a cell is dividing, this DNA becomes visible and forms a number of thin strands called **chromosomes**. Each chromosome carries a large number of particles called genes and it is these **genes** which carry the information from parents to offspring.

In most organisms, there are two sets of chromosomes in each body cell. One set is inherited from the mother and one from the father. The chromosomes in each

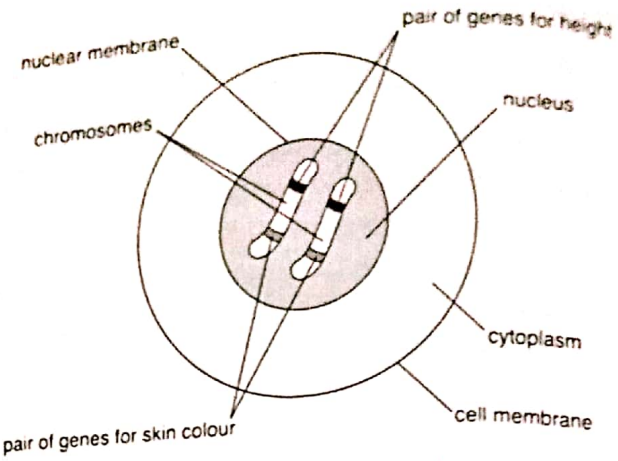


Fig 3.88 One pair of homologous chromosomes showing how genes occur in pairs.

set differ from each other in shape and size, but each has a matching one in the other set. These matching pairs of chromosomes are called **homologous pairs**. The gene controlling a particular characteristic such as height is found at a particular position on each of the homologous chromosomes (Figure 3.88).

There may be several different forms of a gene. Alternative forms of the same genes are called **alleles**. However, each chromosome of the pair carries just one of the alleles, but the pair may have different alleles. For example, in peas, one chromosome may carry the allele for tallness and the other may carry the allele for dwarfness. In this case, the pea will be tall because the allele for tallness is stronger than the allele for dwarfness. The allele which is always expressed when it is present is said to be **dominant** and is written as a capital letter. The allele which is only expressed when the dominant allele is not present is said to be **recessive** and is written as a small letter – in the case of height of peas, they would be written as **T** and **t**.

If an organism has the same two alleles for a characteristic, the term **homozygous** is used (e.g. **TT** or **tt**). If an organism has two unlike alleles it is **heterozygous**, e.g. **Tt**.

Dominant character is therefore the character that expresses itself even in the presence of other characters, e.g. tallness.

Recessive character can be defined as the character that only expresses itself in the presence of its own kind but becomes suppressed or masked in the presence of other characters, e.g. dwarfness.

In heterozygotes the effect of the recessive allele is not seen, but it can still be passed on to the next generation. The genetic make-up of an organism is called its

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genotype (e.g. **TT**, **Tt** or **tt**). **Phenotype** describes the physical characteristics or outward appearance of an organism. It is determined by the genotype and the environment. For example, the phenotypes of **Tt** and **TT** are tall, but that of **tt** is dwarf.

As the chromosomes contain the genes, the sperm contains genes from the father and the ovum contains genes from the mother. When the egg is fertilised and the zygote is formed, it receives two sets of genes, one set inherited from each parent. Thus a baby will receive genetic information from the father and the mother. All children in a family can be seen to be different, and yet they resemble each other and also their parents because the children inherit the genes from both their parents. There are millions of possible combinations of the genes. As a result, there is considerable variation between offspring.

Each individual has a unique combination of genes unlike anyone else in the human species (except identical twins).

Inheritance in peas

By crossing pea plants, as Mendel did, it is possible to study heredity over several generations. If tall plants which breed true (i.e. are homozygous) are crossed with true-breeding dwarf plants and the resulting seeds are sown, all the offspring (first filial generation **or** F_1) are tall. This demonstrates the dominance of the tall allele. In Figure 3.89, 'types of gamete' refers to sex cells such as sperm, ova and pollen grains.

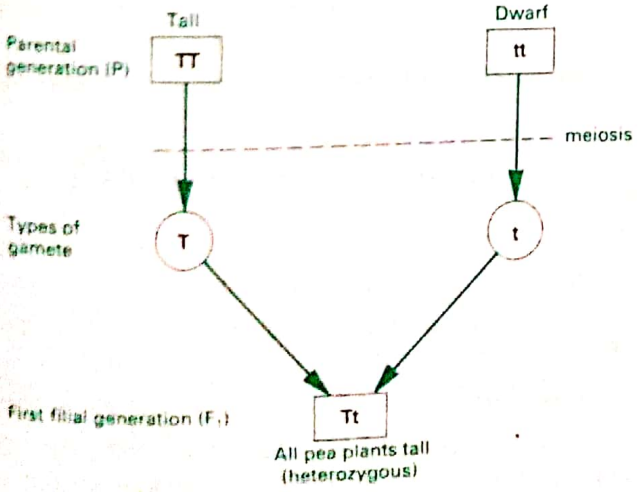


Fig 3.89 Inheritance of height in pea plants to first filial generation.

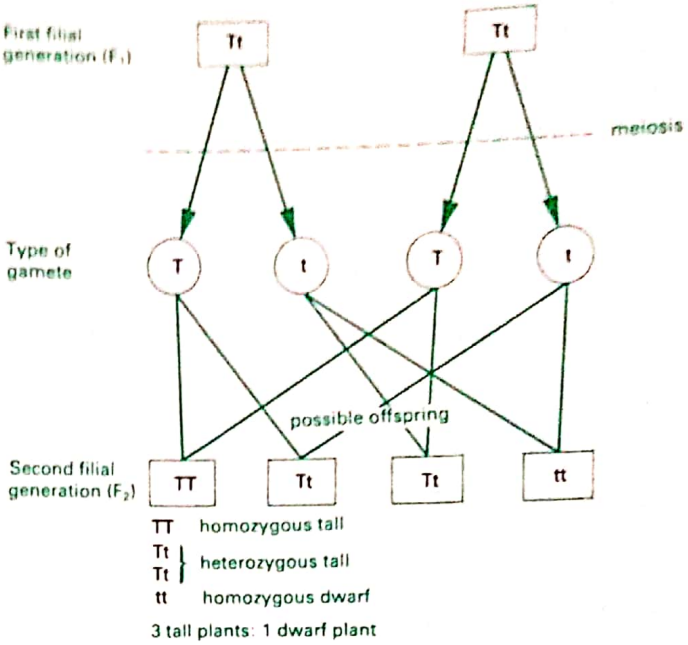


Fig 3.90 Inheritance of height in pea plants from first filial to second filial generation.

The first filial generation (F_1) is the offspring produced by crossing the parental generation. The F_1 plants are then cross-pollinated and the seeds from this cross are grown. They will produce pollen grains of two types, **T** and **t**, and ova of two types, **T** and **t**. Either type of pollen grain could fertilise either type of ovum to produce seeds of the F_2 generation. These are found to produce tall plants and dwarf plants in the ratio 3:1 (Figure 3.90).

Test crossing

A geneticist may want to know the genotype of a tall pea plant. Tall peas can be TT or Tt. If a tall plant is crossed with a dwarf plant the geneticist can discover the genotype of the tall plant.

This is called a test cross. It can be used in plants or animals. The organism to be tested is always crossed with one showing the double recessive of the particular allele – if any of the offspring show the recessive characteristics, the organism being tested is heterozygous.

ACTIVITY 3 Test crossing a heterozygous tall pea and a homozygous dwarf pea

1 Write down the genotypes of the two kinds of pea.

2 Do a cross to show the possible offspring from this cross. What is the ratio of the phenotypes in the offspring?

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3 By doing another cross, prove that if you had used a homozygous tall plant (TT) instead of a heterozygous tall plant (Tt) you would have shown a different result. What are the phenotypes of the offspring now?

This activity shows that dwarf plants are only produced from a test cross if the plant with the dominant phenotype is heterozygous.

Monohybrid inheritance in humans – albinism

Albinism is a condition in humans where there is a failure to produce skin pigments. Albinos therefore have light skin, white hair and pink eyes. They also appear slit-eyed due to their sensitivity to bright light. Albinism is not a disease as albinos are able to live a normal life. It is caused by a recessive gene represented by 'a', with the normal dominant allele as 'A'.

How could two normal parents produce an albino child?

To work this out the information given is used logically. It can be explained point by point:

1 As both parents are normal they must both have a normal allele (A).
2 To produce an albino child, both parents must also have a recessive allele (a).
3 Both parents are therefore heterozygous, Aa. The possible offspring are shown in Figure 3.91.

There is a 25 per cent (1 in 4) chance of an albino child being produced, i.e. 3 normal : 1 albino.

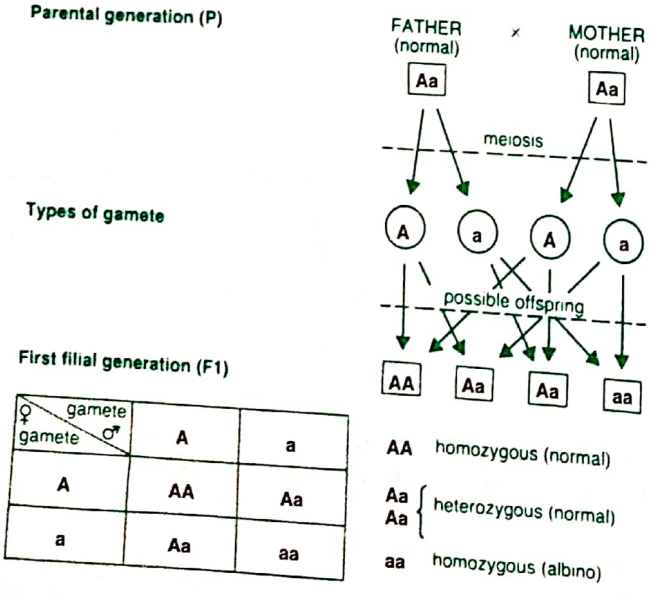


Fig 3.91 Inheritance of albinism from heterozygous parents.

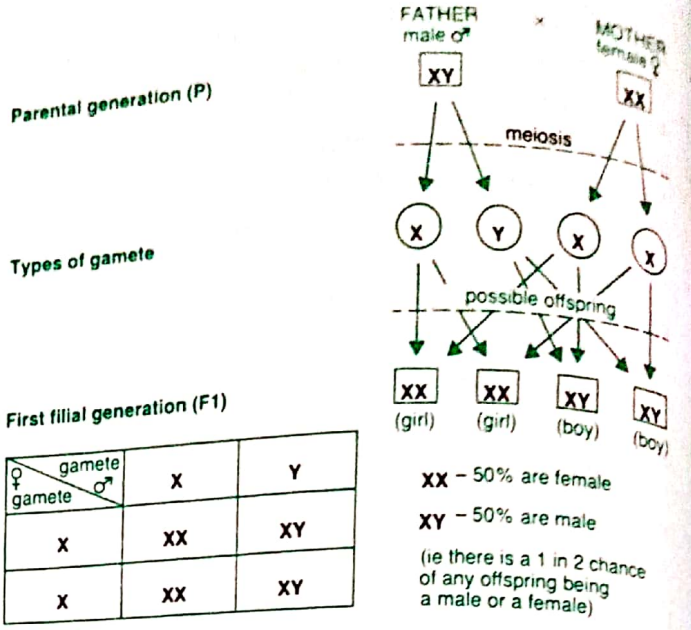


Fig 3.92 How sex is inherited.

Stem cell cloning

Cell cloning refers to the process of making an identical copy of a cell. Stem cell cloning or therapeutic cloning is used to create a clonal embryo for use in research. Stem cells are found in multicellular organisms. They renew themselves through mitotic cell division and differentiate into a diverse range of specialised cell types. The aim is not to create cloned human beings, but to harvest stem cells that can be used to study human development and potentially to treat diseases.

ACTIVITY 4 Stem cell cloning

Work in groups to discuss the ethics of stem cell cloning. Do you agree or disagree with this process?

Sex determination in humans

There are 46 chromosomes in each human cell; 44 of these (22 pairs) are similar in males and females. The remaining pair of chromosomes is called the sex chromosomes. In females the pair looks identical, each is called an X chromosome. In males the sex chromosomes are not the same. Each male has one X chromosome and a shorter Y chromosome. Therefore when considering sex determination the female is represented as XX and the male as XY (Figure 3.92).

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When the two chromosome sets separate during meiosis in males it results in half the sperm containing an X chromosome and half a Y. All the eggs (ova) each receive an X chromosome.

The sex of the offspring is determined by the sperm which fertilises the egg: a Y-bearing sperm will produce a male while an X-bearing sperm produces a female. Notice that due to the random fusion of egg and sperm there is an equal chance of a boy or a girl being conceived each time an egg is fertilised by the sperm.

> Sex is determined at fertilisation. It is the chromosomes of the man that determine the sex of the child.

Sex preference

Certain cultural habits in Ghana cause some parents at a certain time to prefer a male child to a female child or vice versa. Often, this sex preference leads to large families because the parents keep having children in the hope that their wish will be fulfilled. In some cases, family members become disappointed and unhappy if their wishes remain unfulfilled. A couple may blame each other, with the result that the marriage becomes unstable.

Sex-linked characters

The sex chromosomes carry genes that determine certain characteristics that are inherited along with the sex of the individual. Such characteristics are described as **sex-linked**. The human Y chromosome is small and is thought to carry very few genes, if any at all. Thus a gene carried on the X chromosome in the male would not have a corresponding allele on the Y chromosome.

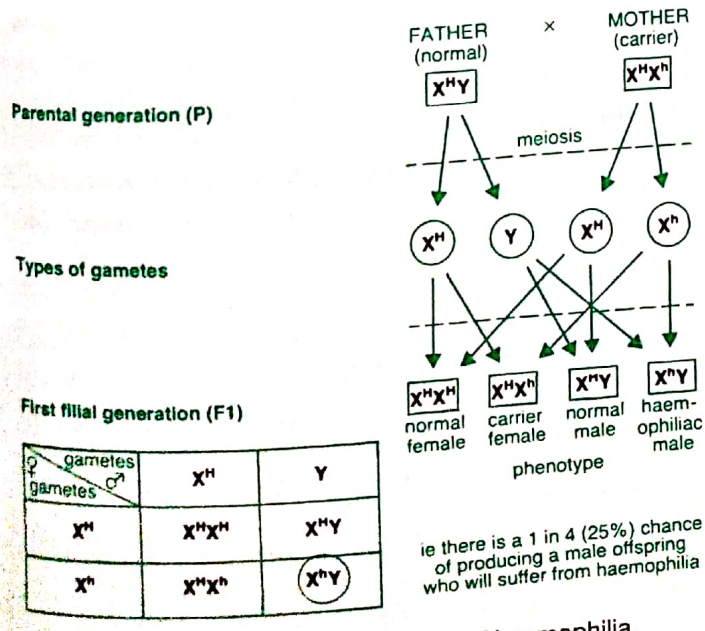
A boy receives his X chromosome from his mother and his Y chromosome from his father. Therefore he cannot inherit sex-linked characteristics from his father. One of the best-known examples of sex linkage is shown by the disease haemophilia in which the blood does not have the ability to clot. The disease is caused by a recessive gene carried on the X chromosome (Figure 3.93).

Female haemophiliacs are rare since they can only be produced when both parents carry the allele. However, a woman with the recessive allele on one of her X chromosomes will act as a 'carrier' of the disease and pass it on to her sons.

If **H** represents the normal allele for blood clotting (dominant), and **h** represents the allele for haemophilia (recessive), a normal man is X^HY, a haemophiliac man is X^hY, a normal woman is X^HX^H or X^HX^h, and a haemophiliac woman (very rare) is X^hX^h. Figure 3.93 shows that outwardly normal parents could produce a haemophiliac son.

From this we can see that there is a 1 in 4 chance of any child being a haemophiliac son – any son has a 50:50 chance of being haemophiliac, and all daughters will be normal, but each daughter will have a 50:50 chance of being a carrier of haemophilia.

Baldness and red/green colour-blindness are two other examples of sex-linked conditions.



♀ gametes / ♂ gametes	X^H	Y
X^H	X^HX^H	X^HY
X^h	X^HX^h	X^hY

Fig 3.93 Sex-linked inheritance of haemophilia.

Blood groups

Blood is grouped according to the presence or absence of certain antigens in the red blood cells and antibodies in the blood plasma. There are four blood groups and every person belongs to one of these blood groups (Table 3.20).

Table 3.20 Blood groups of humans

Genotype	Blood group
AA	A
AO	A
BB	B
BO	B
AB	AB
OO	O

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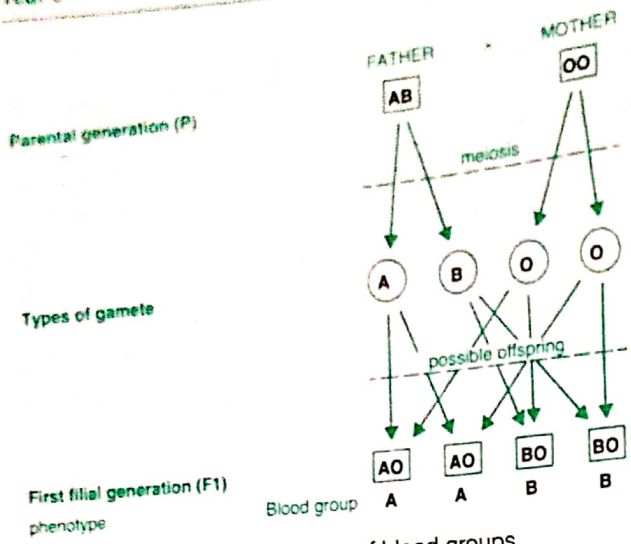


Fig 3.94 Inheritance of blood groups.

In the examples discussed so far, each characteristic is controlled by a gene which appears in two different forms of alleles. There are other conditions where a single characteristic may be controlled by three or more alleles. This is known as the multiple allele condition. Blood grouping in humans is an example. (Note that only two of these alleles can be present in any one individual, one received from each parent).

The blood groups are controlled by three alleles represented by the symbols **A**, **B** and **O**. The alleles **A** and **B** are equally dominant (co-dominant) so that if a person is **AB**, both alleles have an effect, and the person is blood group **AB**. Both **A** and **B** alleles are, however, dominant to allele **O**, so that if a person is **AO** or **BO**, the **O** has no effect, and the person is blood group **A** or blood group **B**. The combination of alleles shown in Table 3.20 determines the blood groups.

Blood grouping has a number of practical applications. It is sometimes used to establish the legitimacy of children. For instance, if one parent has blood group AB and the other has blood group O they cannot have children with blood groups AB or O (Figure 3.94). Blood grouping may also be used to predict blood groups of children if the blood groups of the parents are known.

ACTIVITY 5 Blood grouping

1 The blood groups of offspring with one parent of blood group A and another of blood group B are shown in Figure 3.95. However, this is not the only possibility. Each parent could have one of two possible genotypes.

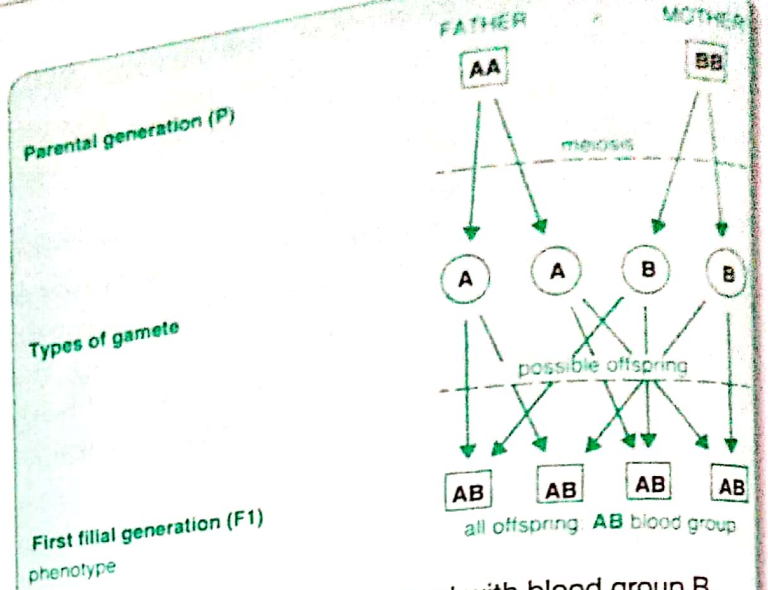


Fig 3.95 Blood group A crossed with blood group B.

2 What are the two possible genotypes for group A and group B?

3 Could two parents of blood group A produce a child of blood group O?

4 How many types of blood group could two parents both of blood group O produce?

5 How many types of blood group could two parents, one of blood group AB and one of group O produce?

Blood transfusion

Each individual can receive blood of his own blood group and everyone can receive blood of group O, as it can mix with all the other groups. It is therefore called the universal donor (see Table 3.21). People with blood group AB can receive blood from any other group. Group AB is therefore called the universal recipient. Giving blood to someone which does not mix with their own can result in the blood agglutinating (forming clumps) and this can be fatal. For this reason in hospitals, blood is only given to a patient if the blood group is known. A simple test can be carried out in order to find the blood group of a patient.

ACTIVITY 6 Blood grouping

1 Using the information you have learned about blood groups, fill in the grid provided (Figure 3.96) ticking the boxes where the donor blood can be given, i.e. where blood groups are compatible.

2 Put a cross in all the boxes where the donor blood cannot be given as it would cause clumping.

3 Check your answers with your teacher.

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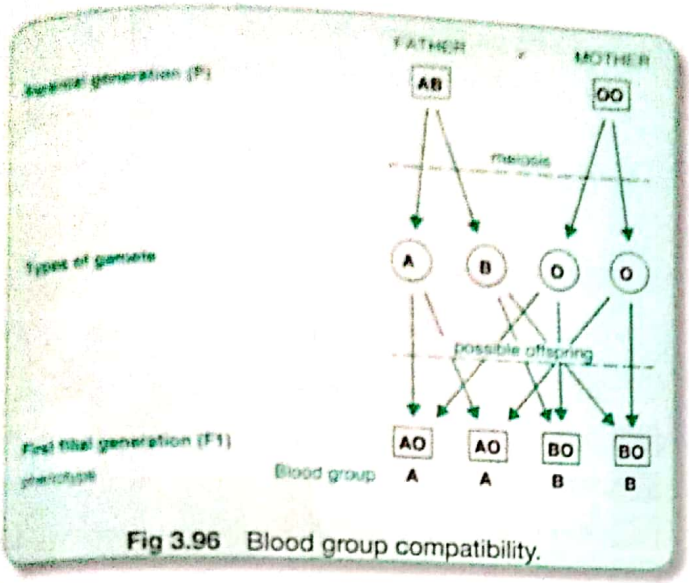


Fig 3.96 Blood group compatibility.

Table 3.21 Blood group compatibilities

Patient's (recipient's) blood group	Antibody present in serum	Donor's blood group			
		O	A	B	AB
O	ab	✓	✗	✗	✗
A	b	✓	✓	✗	✗
B	a	✓	✗	✓	✗
AB	none	✓	✓	✓	✓
Group AB can receive all other groups. Group AB called **universal recipient**		Group O can be given to all other groups. Group O called **universal donor**			

✓ = compatible with recipient
✗ = incompatible with recipient, i.e. agglutination

Rhesus factor

There are other systems of classifying blood besides the ABO system. One is the Rhesus system. This is based on the presence or absence of an antigen called the **Rhesus factor** (Rh factor), which is produced in the red blood cells of the Rhesus monkey. The Rhesus factor is also present in some humans. The allele that causes the presence of the Rh factor is a dominant allele. The recessive allele causes the absence of the Rh factor. The presence or absence of the Rh factor in a person depends on the combination of the alleles. A person may thus be Rhesus positive (Rh^+) or Rhesus negative (Rh^-).

The Rhesus antibody is normally absent in human blood plasma but Rh^- people are induced to produce it when Rh^+ blood is introduced into their body. The Rh^+ antigen reacts with the Rhesus antibody to cause agglutination.

Thus Rh^- people can only receive blood from another Rh^- person. People with the Rh^+ factor can, however, receive blood from Rh^- people. In blood transfusions, the Rhesus system must be considered as well as the ABO system. A person may have blood group A^+, A^-, B^+, B^-, AB^+, AB^-, O^+, or O^-. The positive and negative signs represent the presence or absence of Rh factors. Blood transfusions cannot take place between people who are compatible with regard to the ABO system, but incompatible with regard to the Rhesus system, i.e. A^+ blood cannot be mixed with A^- blood.

The Rhesus factor is inherited. A problem may arise when a Rh^+ man marries a Rh^- woman, especially if the man is homozygous for the Rhesus allele. The foetus inherits this allele from the father and is Rh^+. Fragments of the Rh^+ red blood cells of the foetus containing the Rhesus antigen may move across the placenta into the blood of the Rh^- mother. The white blood cells of the mother are stimulated to produce the Rhesus antibody. This in turn moves across the placenta into the blood of the foetus where it causes agglutination of the red blood cells. The foetus may die as a result, but this is unlikely to happen in the first child. With each successive pregnancy, more Rhesus antibody is produced in the blood of the mother. Subsequent Rh^+ children suffer from massive destruction of their red blood cells. The babies may die due to severe anaemia called haemolytic disease of the newborn. Through advanced techniques in medicine, the lives of these babies can be saved by giving them a transfusion of Rh^- blood. People with Rh^- blood are few. They form about 5 per cent of the total population. Thus women who are Rh^- are rare. In any case it is advisable for would-be couples to undergo blood-grouping tests before starting a family.

Sickle-cell anaemia

In some genetic investigations it has been found that there is not always total dominance of one allele over another. In the heterozygous state one allele may have only partial dominance over the other. One example of partial dominance is found when a human has one allele for sickle cell and one normal allele. They suffer a mild form of sickle-cell anaemia called sickle-cell trait.

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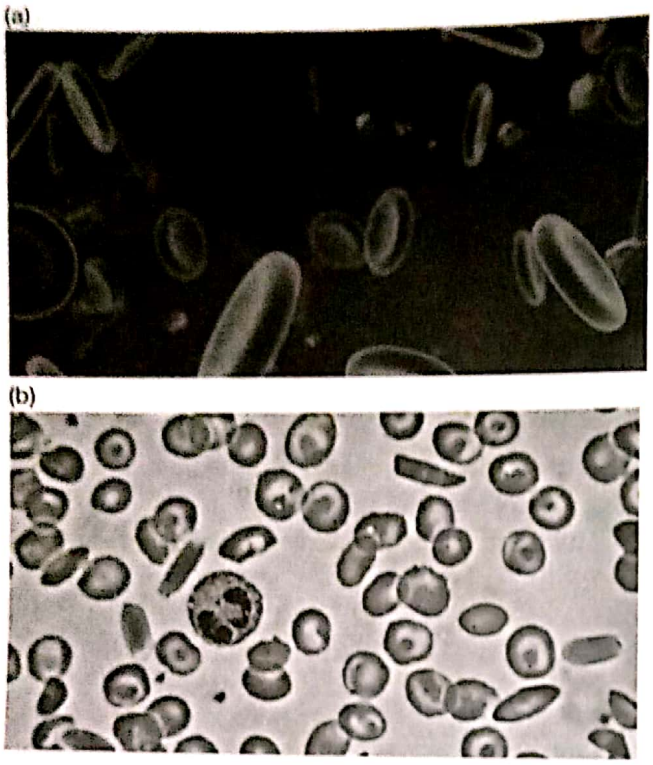


Fig 3.97 **(a)** normal red blood cells, **(b)** sickled red blood cells.

Normal red blood corpuscles are bi-concave discs (see Figure 3.97(a)). They contain a red pigment called haemoglobin. The sickle cell allele causes abnormal haemoglobin to be made. This results in distorted, sickle-celled red blood cells (Figure 3.97(b)).

If a person has both alleles for sickle cell, all the blood cells are affected. If only one sickle cell allele is present, the individuals have sickle-cell trait, with only a proportion of red blood cells affected. This condition is advantageous against malaria. The maps in Figure 3.98 show the relationship between sickle-cell trait and the occurrence of malaria.

It is important that individuals who both carry the recessive allele realise that, if they marry and have children, they have a one in four chance of producing children with sickle-cell anaemia. These children would die from this inherited disease. Up to 30 per cent of the population of Ghana carry the gene for this disease. If **S** = allele for normal red blood cells and **s** = allele for sickle-cells:

- a normal person will have the genotype **SS**
- a person with sickle-cell trait will have the genotype **Ss**

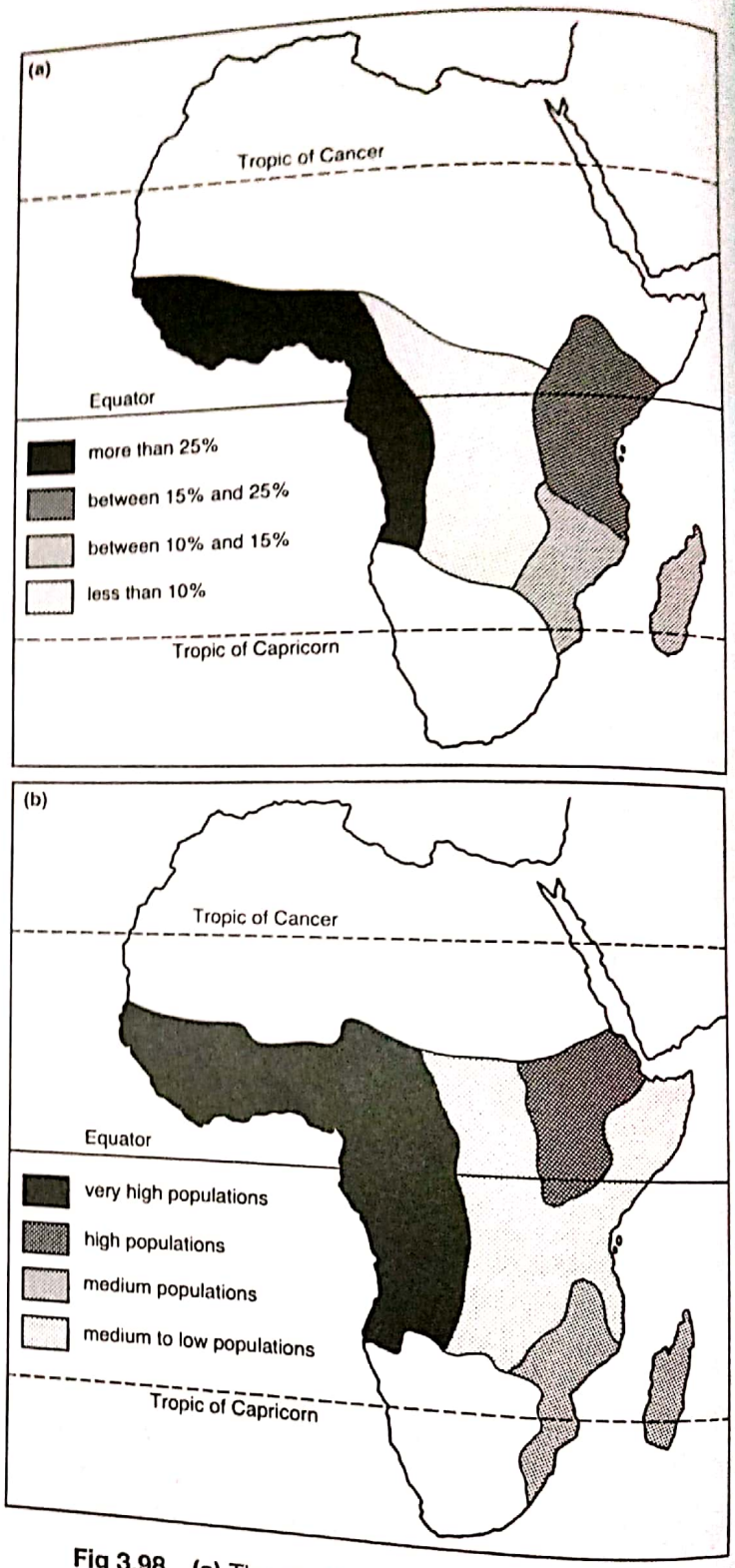


Fig 3.98 **(a)** The distribution frequency of people carrying the gene for sickle-cell haemoglobin. **(b)** The distribution frequency of Anopheles mosquitoes which act as vectors for the organisms causing malaria.

- a person with sickle-cell anaemia will have the genotype **ss**.

If two people with the sickle-cell trait marry each other, there is a possibility of a child with sickle-cell

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anaemia being produced. Counselling is available for people who both have sickle cell anaemia and are considering marriage.

ACTIVITY 7 Sickle-cell inheritance

For two parents with sickle-cell trait, work out the chances of the following children being produced:

a) a normal child
b) a sickle-cell trait child
c) a sickle-cell anaemic child.

Theories of evolution

Evolution is the continuous process by which one form of life evolves or changes into another form over a long period of time.

The theories of evolution argue that the huge variety of organisms present today have slowly developed, or evolved, over millions of years from a few simple life forms. It also explains why there are so many different kinds of organisms. The inherited characteristics of nearly all organisms change from generation to generation. In many instances, the change is so gradual that it becomes noticeable only after many years have passed. Finally, the accumulated changes may become so pronounced that the descendent does not look so much like the remote ancestor. It may belong to a different species.

In 1809, a French professor of zoology, Jean Baptiste Lamarck, put forward a theory to explain the process of evolution. He believed that animals and plants respond to their environment by becoming better adapted to them, e.g. animals living in cold climates grow thicker fur to keep warm. This was based on the observation that parts of the body which are used frequently become more developed, and parts which are not used tend to degenerate. The improvement would then be passed on to offspring and would become more pronounced in future generations until a new species evolved. This theory was known as 'Lamarckism' or 'the inheritance of acquired characteristics'. There was little evidence to support this theory, and no real evidence has been produced to support it to the present day. Lamarck had little knowledge of genetic mechanisms and therefore did not understand genetic continuity.

In 1859, a British naturalist called Charles Darwin put forward his theory of evolution by natural selection. It can be summarised as follows:

- Variation is a characteristic of all living things; even individuals belonging to the same species show many differences.
- Offspring are produced at a rate which could at least double the population of each species at every generation, but as mortality is high, the actual numbers remain fairly constant.
- Many organisms die before they can reproduce – from predation, lack of food, disease, cold, etc. In other words there is a struggle for survival.
- Some variations help individuals to win this struggle and they are able to grow and reproduce.
- Through reproduction, this 'survival value' is passed on to the next generation. Over millions of years these variations build up and may become more pronounced, eventually resulting in the formation (evolution) of a new species by the survival of the fittest.

At the time, Darwin's theory was dismissed by many as blasphemous since it conflicted with the idea of divine creation. His book, *The Origin of Species* contained much evidence to support his theory. Since that time, much more evidence has been found to support the theory of evolution by natural selection.

ACTIVITY 8 Studying natural selection

Look carefully at the photographs in Figure 3.99. Each contains two forms of the peppered moth, *Biston betularia*: the normal form which is speckled white, and the melanic form (produced by a mutation in the gene for wing colour) which is nearly black. In the first photograph, they are both resting on the bark of a lichen-encrusted tree, whereas in the second photograph, they are on the bark of a tree blackened by pollution. It is clear from this that their predators (birds) would be able to pick out their food easily under different conditions.

As the industrial revolution progressed in Britain in the 1950s, it was discovered that the populations of melanic moths were on the increase in industrial areas, whereas the populations of normal coloured moths were on the decline.

Now answer the following questions:

1 Which moth is better camouflaged on:
   a) pale bark
   b) sooty bark?

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2 Which moth would be most likely to survive and produce offspring in:
   a) country areas
   b) industrialised areas?

3 In which areas would you expect the numbers of:
   a) the normal form
   b) the melanic form,

   to increase?

4 Does this example support the theory of evolution by natural selection in your opinion? Give reasons for your answer.

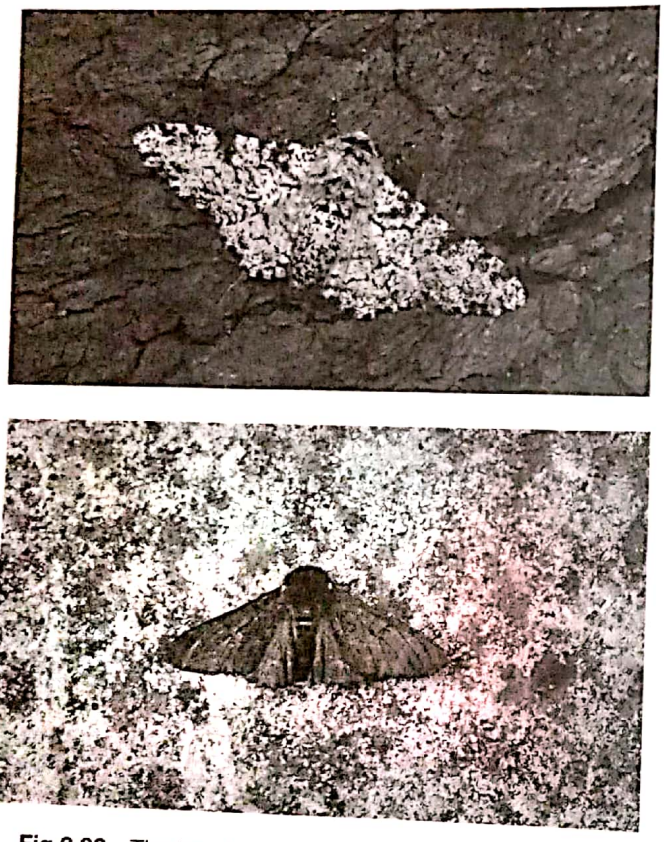


Fig 3.99 The two forms of the peppered moth **(a)** on lichen-covered bark; **(b)** on soot-encrusted bark.

Comparing the theories of evolution

The evolution of the giraffe can be used to illustrate the differences in the two theories. Fossil records show the giraffe to have evolved from an ancestor with a short neck. Lamarckists would say that over millions of years, the giraffe's neck became gradually longer as it continually stretched up in competition with its neighbours to reach foliage. This condition would be passed on to the offspring, and be gradually improved upon with each successive generation. On the other hand, Darwinists would say that in the struggle for survival, giraffes that, by chance, happened to have longer necks than their neighbours were better able to reach food and survive to pass on their advantage to their offspring. This happened in successive generations, resulting in a gradual lengthening of the neck.

Evidence for evolution

There is much evidence in support of evolution. The main sources are from fossil records, geographical distribution, comparative anatomy and embryology.

Fossil records

When an organism dies, its body will normally decay. If, by chance, its body sinks into sediment at the bottom of a river, lake or sea, its soft parts will decay but the hard parts (skeleton) may gradually absorb minerals and turn to stone. This forms a **fossil**. Layers of sediment containing fossils build up over the years and gradually harden into sedimentary rock. Over millions of years, these rocks may be pushed up to the surface and cracked open or weathered, exposing the layers and the fossils within them.

It can be determined which layers of rock are the oldest, and a study of fossils from different layers helps scientists to build up a record of evolutionary change, such as that for the evolution of the horse (Figure 3.100). An evolutionary tree can be drawn up from the study of fossil records. Figure 3.101 is an evolutionary time chart, showing the relative abundance of some plant and animal groups.

Geographical distribution

Many environmental changes in the history of the Earth have probably influenced evolution – ice ages, mountain building, continental drift, etc. The constant spread of organisms by migration and chance dispersal into new environments may have resulted in the evolution of new species, specially adapted to their surroundings. This can be seen by studying the global distribution of various organisms and their various adaptations which suit them to their surroundings.

An illustration of this can be seen in a study of the camel family, the Camelidae. The family is represented in North Africa and Asia by the camel, and in South

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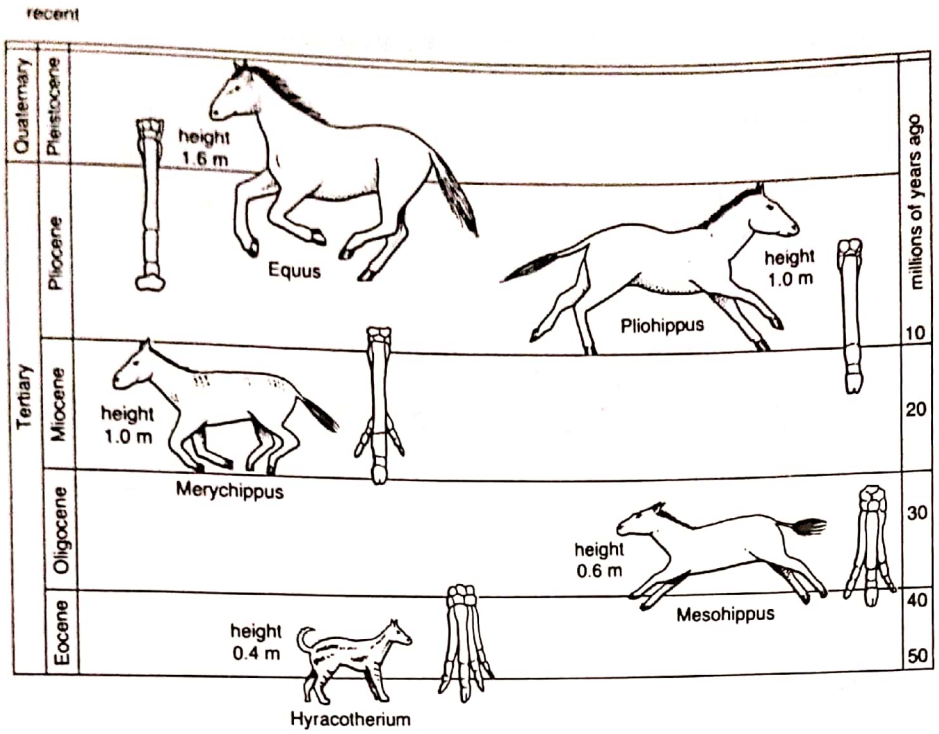


Fig 3.100 Evolution of the horse.

era	period	duration of periods (million years)
Cenozoic	Quaternary	2
	Tertiary	63
Mesozoic	Cretaceous	70
	Jurassic	60
	Triassic	30
Palaeozoic	Permian	55
	Carboniferous	65
	Devonian	50
	Silurian	45
	Ordovician	60
	Cambrian	100

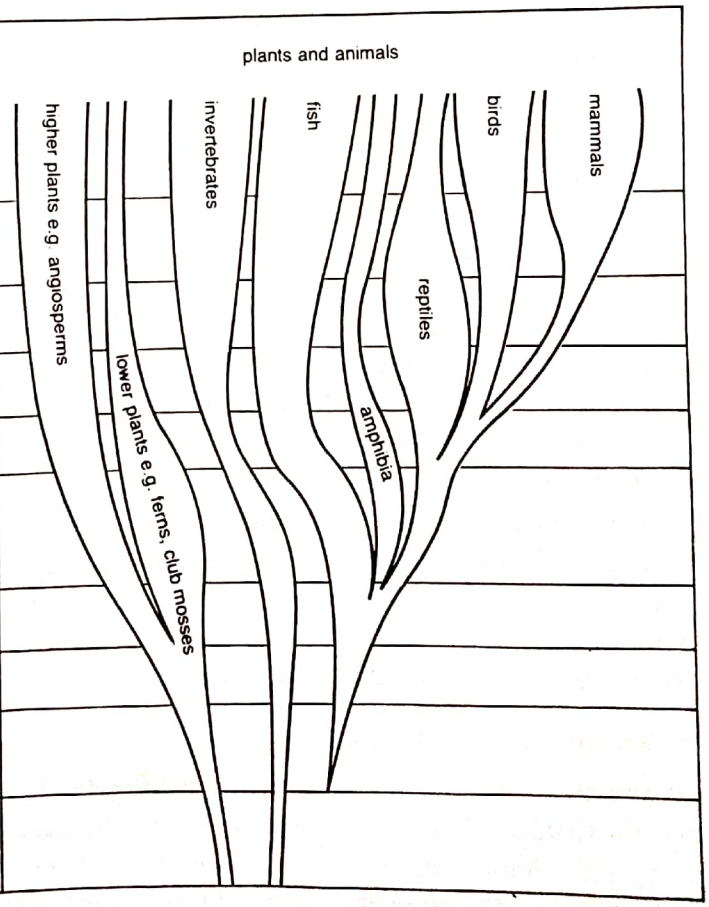


Fig 3.101 Evolutionary time chart.

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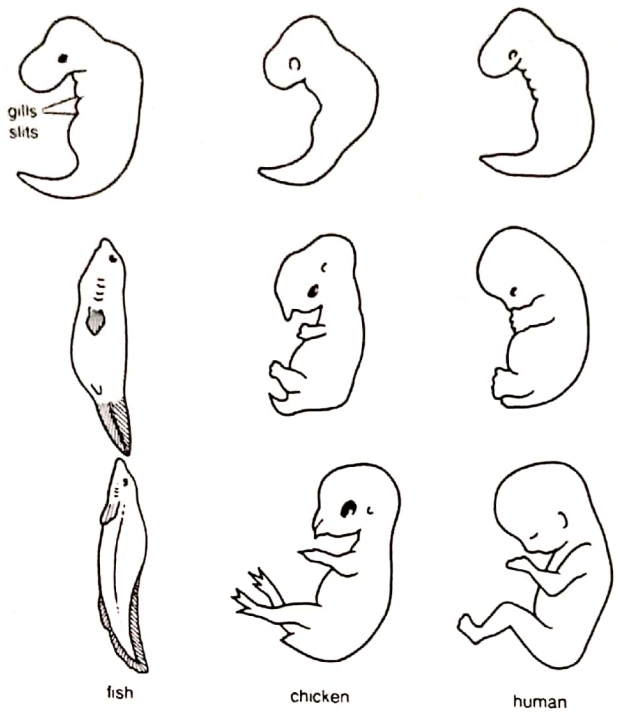


Fig 3.102 Stages in the embryonic development of fish, chicken and human.

America by the llama. Fossil records show the family to have originated in central North America. At that time, it is known that the continents were connected by land bridges. Fossil studies indicate that the ancestors of camels and llamas migrated from North America across these land bridges. When the continents were separated by continental drift, the animals were isolated and evolved along different lines to produce the modern day camel and llama.

Continental drift may also explain the absence of placental mammals in Australia. It became cut off before these mammals reached it and the marsupials therefore evolved without competition and occupy ecological niches which, in other continents, are occupied by placentals. For example, tree kangaroos and koalas occupy the same niches as arboreal monkeys and sloths. In fact, for most placental mammals, there is an equivalent Australian marsupial which has the same lifestyle.

Comparative anatomy

Mammals show vast differences in shape, lifestyle, etc. but the structure (anatomy) of their bodies has the same basic plan. Similarities in the basic pattern of bones in the mammalian forelimb from different mammals suggest that these animals have a common ancestor.

Embryology

The study of stages in the development of embryos from different vertebrates shows similarities in structure, particularly in the early stages, and provides more evidence that vertebrates evolved from a common ancestor (Figure 3.102).

Self check

For questions 1 to 12, choose the letter that refers to the correct option.

1 Which one of the following is not true concerning heritable variation?
- **A** it is determined by genetic make-up
- **B** it is passed on from parents to offspring
- **C** it has many intermediate forms
- **D** it can sometimes be called discontinuous variation

2 Acquired characteristics are
- **A** inherited from parents
- **B** caused by the environment
- **C** examples of genetic variation
- **D** passed on to offspring

3 Which one of the following is an inherited characteristic?
- **A** hair colour
- **B** night-blindness
- **C** scar
- **D** knowledge

4 A homozygous black mouse is mated to a brown mouse. If black is dominant to brown colour, what colour will the young mice be?
- **A** all will be black
- **B** all will be brown
- **C** some will be black and some will be brown
- **D** they will be partly brown and partly black

5 Gametes are produced in
- **A** the eye and the ear
- **B** the kidney and the bladder
- **C** the stomach and the intestine
- **D** the testes and the ovary

6 Genetic information is passed to the next generation
- **A** by mitosis
- **B** by dominance
- **C** on the chromosomes
- **D** by what we eat

7 A test cross is used to check the genotype of
- **A** a dominant phenotype
- **B** a dominant heterozygote
- **C** a recessive homozygote
- **D** a recessive phenotype

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8 In humans, the sex of a baby is determined by the chromosomes in
- A the egg cell
- B the sperm
- C both egg cell and sperm
- D neither egg cell nor sperm

9 Which of the following statements is not true? Evolution
- A is a gradual process
- B may result in the origin of new species
- C does not result in extinction of species
- D may result in extinction of species

10 The only workable theory of evolution was proposed by
- A Lamarck
- B Mendel
- C Fleming
- D Darwin

11 Which one of the following statements is correct? Continental drift is most likely responsible for the
- A presence of placental mammals in Australia
- B absence of placental mammals in Australia
- C presence of marsupials in Australia
- D absence of marsupials in Australia

12 Evidence from comparative embryology in support of evolution shows that
- A embryos of different vertebrates have similar structures
- B embryos of different vertebrates have different structures
- C vertebrates evolved from different ancestors
- D bodies of different vertebrates have different basic body plans

13 a) Describe some examples of variations which occur in animals and plants.
b) Give two examples of
(i) acquired characteristics
(ii) inherited characteristics in humans.

14 Describe the meaning of each of the following terms:
a) homozygous
b) heterozygous
c) allele
d) genotype
e) phenotype
f) dominant
g) recessive.

15 a) What is a chromosome?
b) How many pairs of chromosomes do humans have?

16 What advantage does the sickle-cell trait give to humans?

17 a) Explain why males are more likely to suffer from colour-blindness, haemophilia and baldness.
b) What is meant by saying that someone is a 'carrier' of the factor for haemophilia or colour-blindness?

18 Explain how humans can be blood group A, B, AB or O.

19 a) What is meant by the term co-dominance?
b) A red flower is crossed with a white flower of the same species. When the seeds of the F1 generation are planted, they produce flowers which are pink. Explain why this happens.
c) Two of the pink flowers from the F1 are crossed and produce seeds. If these are planted, what colours would you expect in the flowers and in what proportion would you expect them?

20 In humans, brown eye colour (B) is dominant over blue eye colour (b). A brown-eyed man marries a brown-eyed woman. Explain fully what eye colours their children could have.

21 A woman of blood group B has a child of blood group O. She says that a certain man is the child's father. When tested, his blood group is found to be AB. Could he be the child's father? Explain your answer fully.

22 In humans, albinism (a) is recessive to normal colouring (A). Explain fully how two parents with normal colouring could produce a child who is albino.

23 a) What are fossils and how are they formed?
b) How are fossils used as evidence for evolution?
c) Briefly describe two other sources of evidence for evolution.

24 Compare the theories of evolution put forward by Lamarck and Darwin.

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Year 4

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1 Organic and inorganic compounds

Learning objectives

After studying this unit, you should be able to:

1 classify chemicals as organic and inorganic compounds
2 identify chemical compounds as organic compounds
3 distinguish between neutralisation and esterification
4 identify the sources and application of petrochemicals.

Background information

Compounds which contain the element carbon are described as **organic compounds**. Compounds which do not contain the element carbon are described as **inorganic compounds**.

The definition is useful but not completely accurate. Oxides of carbon, i.e. carbon monoxide (carbon(II) oxide), CO and carbon dioxide (carbon(IV) oxide), CO_2, carbon disulphide, CS_2 and the trioxocarbonate(IV) ion, CO_3^{2-}, all of which contain the element carbon, are regarded as inorganic compounds.

Comparing organic and inorganic compounds

Many inorganic compounds are ionic, for example sodium trioxocarbonate(IV), whereas most organic compounds are covalent. Salt, washing soda and chalk are also examples of inorganic compounds.

Organic compounds are greater in number compared with inorganic compounds. They occur mainly as liquids and gases and to a lesser extent as solids; many have low melting and boiling points. The physical structures of all living things, including the human body, are made up mainly of organic compounds. Organic compounds include such substances as carbohydrates, proteins, hormones, enzymes, fuels, plastics, fats and oils, vitamins, medicines, herbs, drugs, insecticides, pesticides, textiles, dyes and soap.

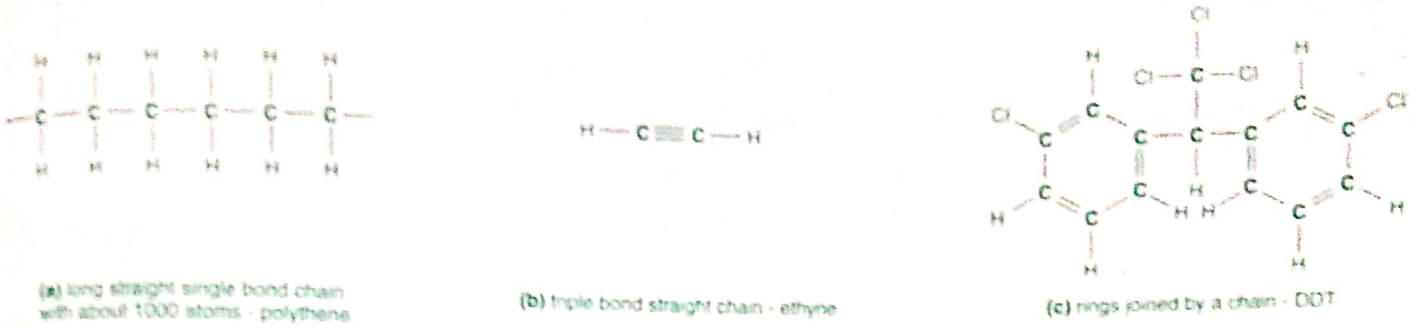
There are natural and synthetic organic compounds. Some natural organic compounds can be made artificially, or synthesised. A larger number which do not exist naturally are synthesised. The list of synthetic organic compounds or products is large and still increasing. Organic compounds present the widest diversity of matter or chemical substances.

The very large number of organic compounds and the possibility of making more are due to the following special characteristics of carbon:

- Carbon is the first member of Group 4 elements of the periodic table; it forms a total of four bonds and is described as **tetravalent**.
- Carbon atoms can combine with each other and hydrogen atoms to form open, straight and branched chains. The chains can be very long with many carbon atoms, for example polymers such as polythene. No other atom can form long chain compounds.
- Carbon can form ring or cyclic compounds.
- Carbon can bond with another carbon atom through stable single, double and triple bonds. No other atom can form stable multiple bonds.
- Carbon can bond with other atoms to form stable compounds.

The combination of these unique properties of carbon has created a large number and diversity of compounds which does not exist in other groups of matter. The carbon atom forms more compounds with other atoms than any other element except hydrogen.

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(a) long straight single bond chain with about 1000 atoms - polythene

(b) triple bond straight chain - ethyne

(c) rings joined by a chain - DDT

Fig 4.1 Examples of organic compounds of carbon.

Figure 4.1 gives examples of common organic compounds of the various descriptions.

There is no definitive number of organic compounds in existence, but some estimates in 2007 suggested around ten million were known – and this number continues to grow. By comparison, there were estimated to be around two million inorganic compounds. The majority of organic compounds contain mainly the elements carbon and hydrogen, with lesser amounts of other elements, such as oxygen, nitrogen and sulphur.

Carbon compounds can be classified into smaller groups based on their different properties. The primary source of synthetic carbon compounds is petroleum. Petroleum is a natural mixture of mainly carbon compounds called hydrocarbons.

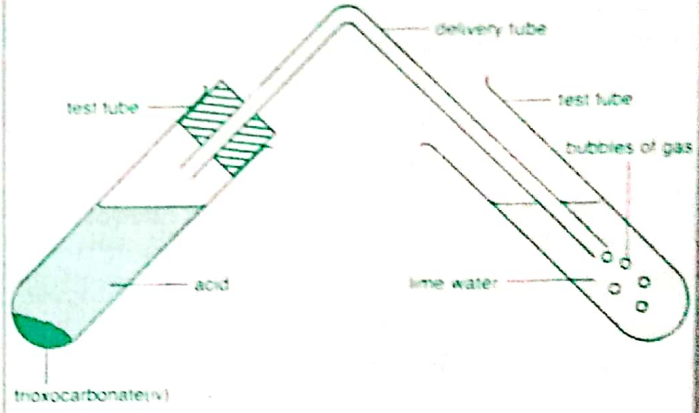


Fig 4.2 Testing a gas with lime water.

ACTIVITY 1 To demonstrate the presence of some elements in some common organic substances

1 a) Cut a piece of bread and put it in a dry crucible lid. Hold the crucible tightly with tongs and heat it gently without the piece of bread catching fire. Heat more strongly without the bread catching fire.
   b) Record the colour of the final product. What element is it? It is a form of carbon, often called charcoal.

2 a) Crush a small piece of dry bread into powder. Mix the bread powder with dry copper(II) oxide. Place the mixture in a hard glass test tube about one quarter full. Get lime water ready to test for carbon dioxide (see Figure 4.2). Heat the mixture gently at first and then strongly.
   b) Test any gas evolved for carbon dioxide, using the lime water.

Caution: Be careful not to allow the lime water to suck into the hot test tube when testing for carbon dioxide.

   c) Test any liquid on the walls of the test tube or any vapour form of it with cobalt(II) chloride paper, to detect water (if water is present its colour changes from pink to blue).
   d) Record the results of your tests. They should have confirmed the presence of both carbon dioxide and water.

3 State at least two elements which are in the bread (note that oxygen could have come from the air and the copper(II) oxide, CuO).

4 Repeat this activity using, e.g. candle wax, dried meat or fish.

ACTIVITY 2 Identifying and listing organic and inorganic substances

1 Locate not less than 40 products or substances in the home, market, pharmacy shop, laboratory or any other suitable stocking point or shop.

2 a) Identify them as organic or inorganic compounds.
   b) Where possible, write the chemical formula of the main component of each compound.
   c) Give a reason why you classified them as organic or inorganic compounds.
   d) State at least one use of each compound.

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3 List your results in a table like the one below.

Substance	Organic or inorganic?	Chemical formula	Place found/use
bread			

4 Discuss the differences between organic and inorganic compounds.

5 Name at least 15 naturally occurring organic compounds and state where they are usually found and their uses.

ACTIVITY 3 Importance of organic chemistry in industrialisation

1 *Work in groups* to discuss the importance of organic chemistry in industrialisation.

2 Write a group report and present to the class.

Organic compounds

Hydrocarbons

A **hydrocarbon** is an organic compound that contains the elements carbon and hydrogen only. Hydrocarbons can be divided into two groups namely the **open chain** and **ring or cyclic**. The open chain hydrocarbons are made up of: **alkanes** – hydrocarbons with only single bonds and the general formula C_nH_{2n+2}; **alkenes** – hydrocarbons with at least one double bond and the general formula C_nH_{2n}; **alkynes** – hydrocarbons with at least one triple bond and the general formula C_nH_{2n-2} where n is a whole number.

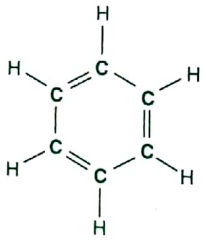
The cyclic hydrocarbons have a ring structure. They are **alicyclic**, and contain carbon atoms bonded by single, double or triple bonds. **Aromatic hydrocarbons** also have a ring structure but their bonding is different (see Figure 4.4).

Hydrocarbons serve as the parent of all other organic compounds.

All members of a hydrocarbon group have similar properties; a group is also called a family of compounds or a **homologous series.**

These compounds are named according to the number of carbon atoms and the family name. For example, the alkane with four carbon atoms is called butane from the prefix 'but-' which means four and the suffix '-ane', the family name for an alkane. They are made up of straight or branched carbon chains (Figure 4.3).

Benzene is an example of an aromatic molecule. Its formula is C_6H_6 and its structure is shown in Figure 4.4a. The symbol shown in Figure 4.4b is often used to represent the benzene ring. Aromatic hydrocarbons are not discussed in detail in this book.



(a)

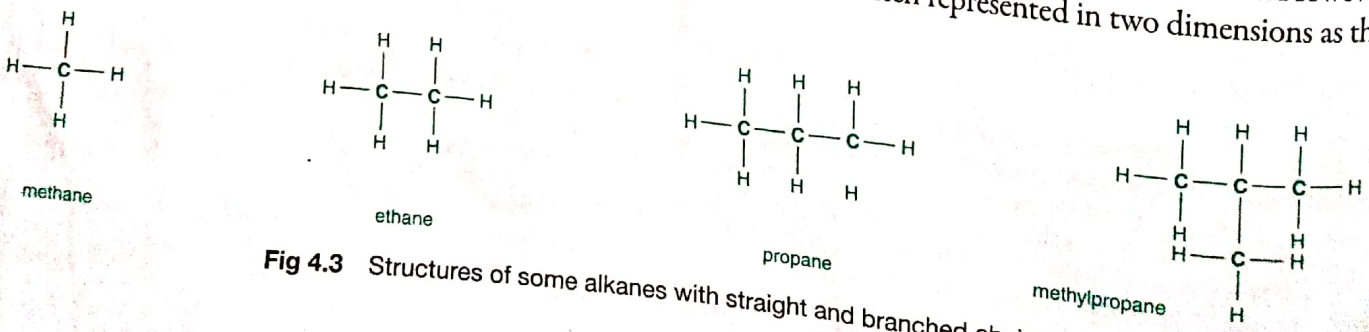


(b)

Fig 4.4 Benzene ring.

Structure and naming of alkanes and other organic molecules

In simple terms, the structure of an organic molecule is the way the atoms are arranged in space. The best way to show the structure of molecules is in three dimensions. However, they are more often represented in two dimensions as this



methane ethane propane methylpropane

Fig 4.3 Structures of some alkanes with straight and branched chains.

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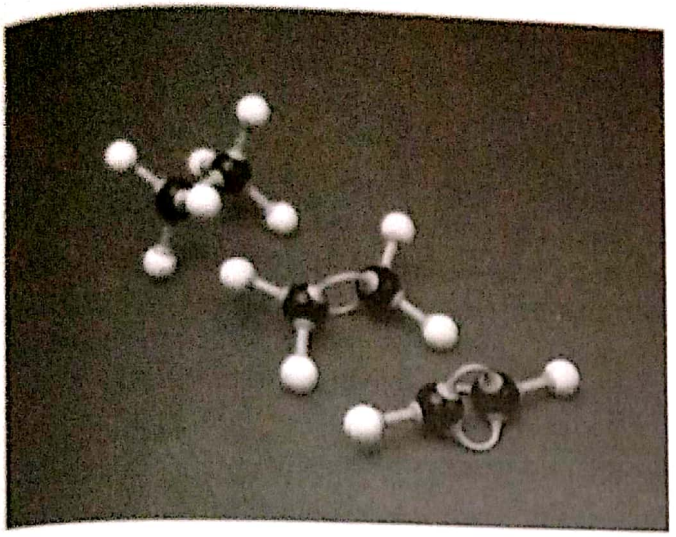


Fig 4.5 Three-dimensional representations of some organic molecules.

is easier to draw. Sometimes the angles between bonds may also be shown. Figures 4.1, 4.3 and 4.4 show two-dimensional representations and Figure 4.5 shows three-dimensional representations of the structures of some organic molecules. Look at the diagrams and check that each carbon atom has four covalent bonds.

The naming of an organic molecule is derived from the structure and the name of the alkane with the same number of carbon atoms in its longest continuous chain. The longest continuous carbon chain serves as the root, backbone or skeleton of the alkane or other organic molecule.

As already mentioned for butane, the number of carbon atoms is indicated by the beginning of the name, or prefix. For example chains containing two and four carbon atoms are given the prefixes '**eth-**' and '**but-**' respectively. The full name of a straight chain alkane molecule without any branching is the combination of the prefix and the family or group suffix '**-ane**'. Examples are shown in Table 4.1.

Substituents

Any atom or group of atoms which replaces a hydrogen atom on a main chain is known as a **substituent**. Substituents in alkanes are often part of alkanes called **alkyl** groups, and serve as branches.

The occurrence of the substituent methyl group in a typical organic molecule (methyl propane) is shown in Figure 4.3.

Table 4.1 Naming an alkane from its prefix and suffix

Number of carbon atoms (n)	Prefix	Alkane	Formula	Molecular structure
1	meth-	methane	CH_4	CH_4
2	eth-	ethane	C_2H_6	CH_3CH_3
3	prop-	propane	C_3H_8	$CH_3CH_2CH_3$
4	but-	butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
5	pent-	pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
6	hex-	hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
10	dec-	decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$

Other types of substituent include halogens, for example chlorine ('chloro') and functional groups.

Functional groups

Alkanes contain a carbon atom surrounded by the maximum of four single bonds and cannot add any more single bonds in a chemical reaction. If two or four hydrogen atoms are removed from an alkane, a carbon-carbon double or triple bond can be formed giving rise to an alkene or an alkyne respectively. The number of carbon atoms in the original chain of the alkane remains the same so the prefix of the name also remains the same.

It will be noted (Figure 4.6) that the suffix in the name of the parent alkane, propane, is replaced by the suffixes '**-ene**' and '**-yne**' to get the name of the alkene and alkyne respectively. The same occurs for any alkene or alkyne with a known number of carbon atoms in the main chain. Propene and hexyne are the alkene and alkyne derivatives of propane and hexane respectively. Alkene molecules contain a carbon-carbon double bond, C=C, while alkyne molecules contain a carbon-carbon triple bond, C≡C.

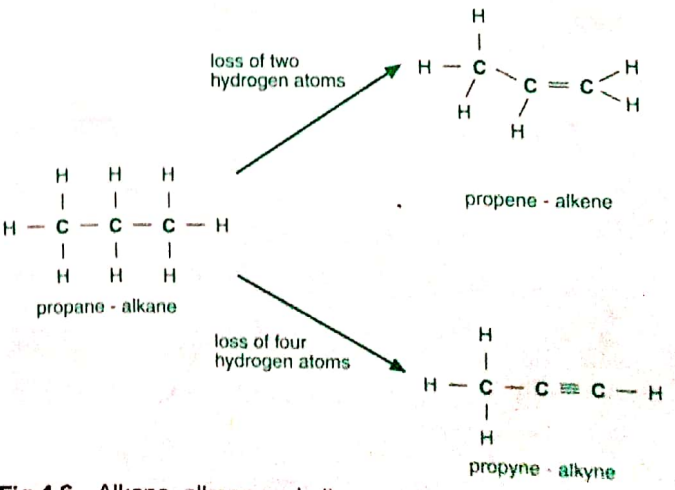


Fig 4.6 Alkane, alkene and alkyne with three carbon atoms.

Alkenes and alkynes are much more chemically reactive at ordinary temperatures than alkanes. Both alkenes and alkynes are described as **unsaturated** hydrocarbons. This is because they can undergo addition reactions in which hydrogen, and other atoms, can add across the carbon-carbon double, or triple bond.

One or more of the hydrogen atoms in an alkane may be replaced in a substitution reaction by a functional group of atoms. For example, when one hydrogen atom of methane, CH_4, is replaced with a hydroxyl group, –OH, the result is the compound methanol, $CH_3–OH$. The hydroxyl group is the functional group. It is the functional group of a compound that determines much of its chemistry. The double and triple bonds of alkenes and alkynes are sometimes considered to be functional groups.

> A **functional group** is an atom, or group of bonded atoms, which gives an organic molecule its characteristic chemical reactions. A functional group is part of a molecule and does not exist on its own. The overall physical and chemical properties of any organic molecule depends on both the nature of the carbon chain and the functional group.

Generally, an organic molecule can be represented as an unreactive alkyl chain and a reactive functional group, such as R–OH. Organic compounds with the same functional group have the same or similar chemical properties. They can be described as a family of molecules and can be distinguished from other families or functional groups by the different observable chemical changes they undergo.

Functional groups are indicated with suffixes, which are often one, two or three letters, replacing the '-e' or '-ane' of the alkane, such as the alkanol, methanol. The names, structures, functional group suffixes and examples of their molecules are shown in Table 4.2.

Reactions of the hydrocarbons

Alkanes are described as **saturated** hydrocarbons because they contain carbon atoms surrounded by four single bonds. They cannot add any more bonds in a chemical reaction. They can undergo **substitution** reactions, in which another atom, for example the halogen chlorine, replaces one or more hydrogen atoms, but only in the presence of ultraviolet light.

Substitution reactions

The equation for the reaction of chlorine (in chlorine water) with methane, CH_4, is:

$$CH_4 + Cl_2 \xrightarrow{\text{ultra-violet}} CH_3Cl + HCl$$

the product is chloromethane. If the reaction continues two, three and four hydrogens can be replaced with chlorine.

Alkenes and alkynes are more reactive than alkanes. They have carbon-carbon double and triple bonds

Table 4.2 Groups of organic chemicals

Functional group or family name (traditional names)	Suffix	Functional group	General formula (R = alkyl chain)	Examples:	
				Formula	IUPAC name (traditional name)
alkanes (paraffins)	-ane		C_nH_{2n+2}	CH_4 C_8H_{18}	methane octane
alkenes (olefines)	-ene		C_nH_{2n}	$CH_2=CH_2$ $CH_3–CH=CH_2$	ethene (ethylene) propene (propylene)
alkynes (acetylenes)	-yne	–C≡C–	C_nH_{2n-2}	HC≡CH $CH_3–CH_2C≡CH$	ethyne (acetylene) butyne
alkanols (alcohols)	-ol	–OH	R–OH	CH_3OH C_2H_5OH	methanol (methyl alcohol) ethanol (alcohol)
alkanoic acids (carboxylic acids or fatty acids)	-oic	–COOH	R–COOH	HCOOH C_3H_7COOH	methanoic acid (formic acid) butanoic acid (butyric acid)
alkyl alkanoates (esters)	-oate	–CO–O–	R–CO–OR′	$HCOOCH_3$ CH_3COOCH_3	methyl methanoate (methyl formate) ethyl ethanoate (ethyl acetate)

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respectively. The carbon atoms do not have the maximum of four atoms directly bonded to them. In some chemical reactions, they add hydrogen or other suitable atoms to become saturated, that is to form stable alkanes. Such reactions are called **addition** reactions. Alkenes and alkynes are described as **unsaturated** hydrocarbons. Like alkanes they also react with halogens but by addition; these reactions do *not* need the presence of ultraviolet light.

Combustion

All hydrocarbons burn in air to give carbon dioxide and water (steam). Alkanes burn with a clear, non-sooty flame; alkenes and alkynes, because of their higher carbon content, burn with a sooty flame. The equations for the combustion of methane, CH_4, and ethene, C_2H_4, are:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$$

These **combustion** reactions give out heat, which is why hydrocarbons are used as fuels, especially those with a low carbon content.

Addition reactions

The following are some examples of addition reactions of ethene:

- hydrogenation (addition of hydrogen); the equation is:

$$C_2H_4(g) + H_2(g) \xrightarrow{H_2SO_4} C_2H_6(g)$$

- catalytic hydration (addition of water); the equation is:

$$C_2H_4(g) + H_2O(g) \xrightarrow{H_2SO_4} C_2H_5OH(l)$$

- addition of **bromine**; the equation is:

$$C_2H_4(g) + \underset{\text{brown}}{Br_2(l)} \rightarrow \underset{\text{colourless}}{BrC_2H_4Br(l)}$$

- polymerisation (adding ethene molecules to each other to form long chains); the equation is:

$$nC_2H_4(g) \xrightarrow[\text{high pressure}]{\text{heat}} \left(-\mathrm{CH_2}-\mathrm{CH_2}-\right)_n$$

the product is **polyethene**, commonly known as polythene.

Some fats and oils, for example palm oil, contain unsaturated hydrocarbon parts. Margarine is produced by reacting these oils with hydrogen over a nickel catalyst to make the oils less unsaturated. This hydrogenation 'hardens' the oil.

Alkynes undergo similar addition reactions. The addition reaction with bromine is a convenient **test for unsaturated hydrocarbons**. When an alkene or alkyne is shaken with bromine water the solution changes from brown to colourless as shown in the equation above.

Some sources and uses of hydrocarbons

The chief source of hydrocarbons is petroleum. Other sources are natural gas, coal and living tissues. Natural rubber, for example, is a hydrocarbon obtained from the rubber tree (Figure 4.7). Rubber is made up of thousands of molecules of a hydrocarbon called isoprene, all joined together. Natural rubber is grown at rubber plantations and used to manufacture tyres. Rubber can also be artificially produced from petroleum products. This is called synthetic rubber. Rubber is used mainly in manufacturing tyres and footwear.

Large quantities of hydrocarbons obtained from petroleum distillation are used directly as fuels and for producing other important and useful organic compounds. Table 4.3 gives some common uses of hydrocarbons.

Table 4.3 Uses of some hydrocarbons

Hydrocarbon	Uses
propane	gas fuel for heating
ethene	manufacture of polymers, e.g. polythene and polychloroethene, common name polyvinylchloride (PVC)
butane	cooking gas, heating furnaces
kerosene	fuel for lamps, stoves and jet planes
petrol	fuel for homes, cars and other vehicles
diesel oil	fuel for diesel engines, heating furnaces
ethyne (acetylene)	oxy-acetylene torches for welding, and for miners' and hunters' lamps

Hydrocarbons are used mainly as fuels because when they undergo combustion in air, heat is produced. The lighter gases, which give out more heat, are suitable for use as fuels in the home. Examples of these are propane, C_3H_8 and butane, C_4H_{10}. LPG (liquefied petroleum gas) used as a fuel in Ghana, contains mainly butane. The equations for these combustion reactions are:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) + \text{heat}$$

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g) + \text{heat}$$

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Fig 4.7 The rubber tree and some of its products.

Alkanols

Alkanols contain the functional group –OH; they are named by replacing the last letter of the name of the parent alkane with the ending '-ol'. Thus ethanol is the alkanol derived from ethane. Alkanols have the general formula $C_nH_{2n+1}OH$, where n is the number of carbon atoms.

For example, when n is one, the formula is CH_3OH which is methanol. The next alkanol in the series is ethanol, C_2H_5OH. Ethanol may be made by fermenting sugar solutions such as sugar cane syrup and pineapple juice. It is separated from the mixture by distillation.

Lower alkanols, that is alkanols with few carbon atoms, such as methanol, ethanol and propanol, are liquids. They are very soluble in water; their aqueous solutions do not change litmus paper or solution – they are neutral to litmus.

Alkanols undergo many chemical reactions due to the presence of the hydroxyl, –OH, functional group attached to a carbon atom on the carbon chain. All alkanols react in a similar way because of the presence of this functional group. Using ethanol, C_2H_5OH, as an example, here are some of the important reactions of alkanols.

Reactions of alkanols

Dehydration (removal of water)

This is the reverse of the hydration of ethene to form ethanol. The reaction can be used to produce ethene in the laboratory. It requires concentrated textraoxosulphate(VI) acid and heat.

The equation is:

$$C_2H_5OH(l) - H_2O(l) \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4} C_2H_4(g)$$

Oxidation/combustion

Ethanol is used as a fuel in lamps and in some countries, such as Brazil, it is mixed with petrol for use in internal combustion engines. It reduces the amount of petrol used, which is useful in conserving petrol which is not a renewable source of energy. The equation for the combustion is:

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$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) + \text{heat}$$

Slow oxidation of ethanol takes place in air. This reaction is responsible for the souring of palm wine when left for a few hours. The sour, vinegary taste is due to the ethanoic acid, CH_3COOH, formed. The equation is:

$$C_2H_5OH(l) + O_2(g) \rightarrow CH_3COOH(l) + H_2O(l)$$

In the laboratory, this oxidation of ethanol to ethanoic acid can be speeded up in the presence of warmth and acidified, aqueous potassium tetraoxomanganate(VII), $H^+/KMnO_4(aq)$, in which case the colour of the latter turns from purple to colourless.

Esterification

This is discussed under 'Alkyl alkanoates (esters)' and 'Neutralisation and esterification'.

Uses of alkanols

Ethanol is an important constituent of alcoholic drinks, for example wine, beer and spirits. Fermented sugar or starch solutions can produce up to 14 per cent aqueous solution of ethanol. A higher percentage of ethanol kills the yeast organisms used in the fermentation process. Distillation is needed to increase the proportion of ethanol in the aqueous solution.

Ethanol is often used in the form of methylated spirits as a preservative or a sterilising liquid because it kills harmful bacteria. It is used to sterilise the skin before injections are given in hospitals. It can also be used to sterilise medical instruments. Methylated spirits is ethanol to which small quantities of methanol have been added.

Ethanol is used on a large scale in industry as a solvent and to produce other important and useful chemicals, for example ethanoic acid. It is usually produced as industrial methylated spirits, which is 95 per cent ethanol and 5 per cent methanol.

Alkanoic acids

Alkanoic acids contain the functional group –COOH. Many of them occur in nature – in plants and animals. Alkanoic acids have the general formula $C_nH_{2n+1}COOH$.

When n is 2 the formula is C_2H_5COOH. In this compound there are three carbon atoms in the chain, therefore its name is propanoic acid. The sour taste of alkanoic acids and the effect of changing blue litmus to red is due to the ionisation of the –COOH functional group to form hydrogen ions. The equation for ethanoic acid, CH_3COOH, is:

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$$

The –COOH functional group makes the alkanoic acid more reactive than the related alkane.

Alkanoic acids are named by replacing the last letter '-e' of the parent alkane with the ending '-oic'. Butanoic acid is the alkanoic acid with the same number of carbon atoms as butane. Table 4.4 gives examples of some alkanoic acids which occur in nature.

Table 4.4 Some naturally occurring alkanoic acids

Acid	Formula	Source
methanoic acid (formic acid)	HCOOH	bee and ant stings
ethanoic acid (acetic acid)	CH_3COOH	vinegar, sour wine and palm wine
citric acid	$C_3H_4(OH)(COOH)_3$	orange, lemon, grapefruit
lactic acid	$CH_3CH(OH)COOH$	sour milk, animal muscles
octadecanoic acid (stearic acid) (Figure 4.8)	$CH_3(CH_2)_{16}COOH$	animal and plant fats and oil, e.g. tallow
octadecenoic acid (oleic acid)	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	olive oil, pork fat, groundnut oil
hexadecanoic acid (palmitic acid) (Figure 4.9)	$CH_3(CH_2)_{14}COOH$	palm oil, animal and plant fats and oils

Alkanoic acids are commonly called 'fatty' acids; many were originally obtained mainly from fat sources (see Table 4.4). Ethanoic acid is a short chain fatty acid, whilst octadecanoic acid (stearic acid) is a long chain fatty acid with a straight chain containing 18 carbon atoms. The long chain fatty acid can be obtained from large molecules of esters in fats and oils. The lower alkanoic acids, up to propanoic acid, are liquids with a sharp vinegary smell. Up to butanoic acid they are very soluble in water. The aqueous alkanoic acids behave chemically as dilute mineral acids due to the functional group –COOH. The common reactions of alkanoic acids are summarised below, using ethanoic acid as an example.

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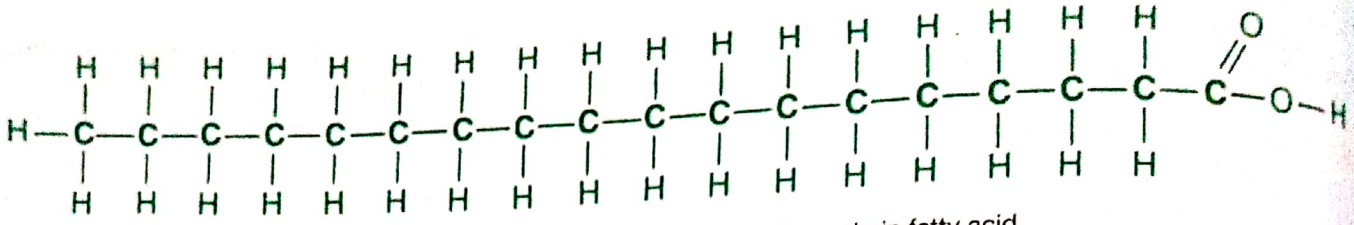


Fig 4.8 Octadecanoic acid (stearic acid) is a long chain fatty acid.



Fig 4.9 Palm fruit is a source of hexadecanoic acid (palmitic acid).

Reactions of alkanoic acids

Reaction with reactive metals

Hydrogen gas and the salt of the metal are the products. The salt of zinc is zinc ethanoate, $(CH_3COO)_2Zn$. The equation is:

$$2CH_3COOH(aq) + Zn(s) \rightarrow (CH_3COO)_2Zn(aq) + H_2(g)$$

Neutralisation with alkalis

Water and a salt, the typical products of neutralisation, are produced. The salt of sodium is sodium ethanoate, CH_3COONa. The equation is:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

Reaction with trioxocarbonate(IV) or hydro-gentrioxocarbonate(IV)

Carbon dioxide gas effervescence is the main observation made in this reaction. The reaction is used to **test for alkanoic acids**. The equations are:

$$Na_2CO_3(s,aq) + 2CH_3COOH(aq) \rightarrow 2CH_3COONa(aq) + CO_2(g) + H_2O(l)$$

$$NaHCO_3(s,aq) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + CO_2(g) + H_2O(l)$$

Esterification

This is discussed under 'Alkyl alkanoates (esters)' and 'Neutralisation and esterification'.

Uses of methanoic and ethanoic acids

Ethanoic acid is used:

- as vinegar in food flavouring
- to make cellulose ethanoate for use in lacquers, varnishes, cinema films and some synthetic fibres such as rayon (Figure 4.10)
- in laundries for brightening colours
- as a solvent to dissolve other carbon compounds
- in the production of drugs and other chemicals
- for cleaning dirty metal surfaces in the home.

Methanoic acid is used:

- as a drying agent in making textiles
- to remove calcium trioxocarbonate(IV) (chalk) deposits, i.e. kettle fur from containers
- as a starting chemical to produce other chemicals.

Alkyl alkanoates (esters)

Esters are the products of the reaction between an alkanol and an alkanoic acid. The general formula for an ester can be represented as RCOOR'.

If the acid is represented as RCOOH and the alkanol as R'OH the equation for the reaction is shown in Figure 4.11.

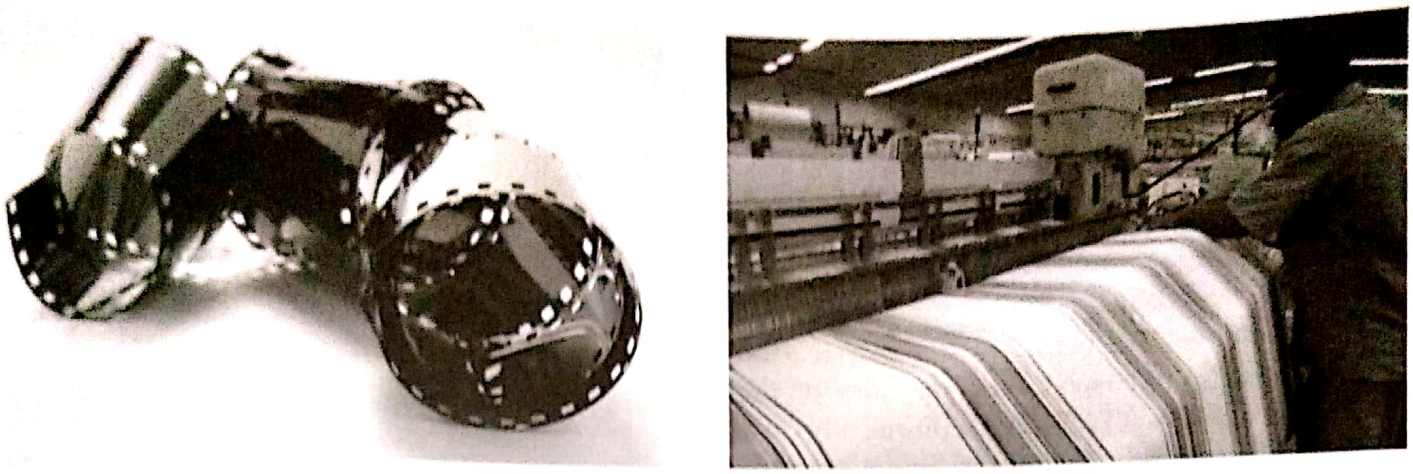


Fig 4.10 Ethanoic acid is used in the manufacture of film strips, fibres and many other articles.

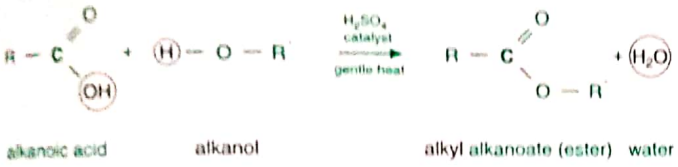


Fig 4.11 Equation for the formation of an ester.

To write the correct structure of the ester (alkyl alkanoate), note that the alkanoic acid loses the –OH group, and the alkanol loses the –H atom.

Esters are named by combining their alkanol and alkanoic acid parts; the alkyl of the alkanol is stated first, followed by the acid name with the '-oic' replaced by '-oate'. Thus when ethanoic acid, CH_3COOH, reacts with propanol, C_3H_7OH, propyl ethanoate, $CH_3COOC_3H_7$, is formed; the equation is as shown in Figure 4.12. The alkyl group of propanol is propyl and the acid part of ethanoic acid becomes ethanoate, giving the full name propyl ethanoate to the ester formed. The reaction takes place quickly in gentle heat, in the presence of concentrated tetraoxosulphate(VI) acid, H_2SO_4, acting as a catalyst.

Characteristics and uses of esters

Esters are generally pleasant to smell. The characteristic smell of different esters makes it possible to identify them. Esters occur naturally in flowers and fruits, such as pears, bananas and pineapples, giving them their pleasant, fruity smell (Figure 4.13). The pleasant smells of the flowers of frangipani, queen of the night and thumbergia are believed to be due to the presence of esters. Bananas which are allowed to ripen have a pleasant smell which can be detected even at a good distance. The smell is due to a mixture of natural esters in the banana.



Fig 4.13 Many fruits contain esters.

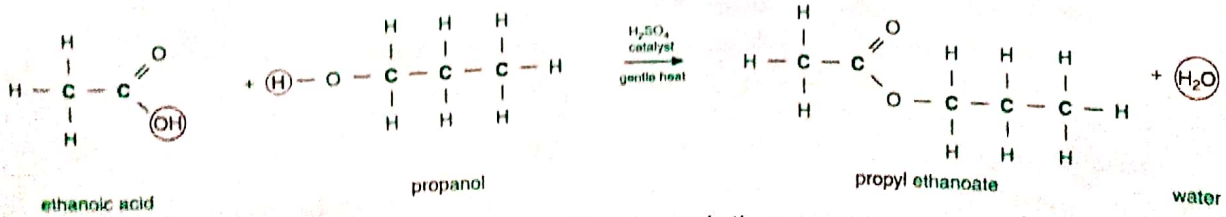


Fig 4.12 Formation of propyl ethanoate.

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Chemists produce esters synthetically to use as flavours in food preparations and cosmetics. Usually, they are a blend of many esters and other fine smelling solvents. Esters are good solvents for paints and other organic substances such as nail polish.

Fats and oils

Fats and **oils** contain both acid and alkanol parts which makes them esters. They are esters of the glycerol, propanetriol, $C_3H_5(OH)_3$ (Figure 4.14) and long chain fatty acids. Fats usually have a saturated hydrocarbon chain and exist as solids whilst oils have an unsaturated hydrocarbon chain and exist as liquids.

When one or more hydrogen atoms of the glycerol's -OH groups is replaced by a long chain fatty acid alkanoate, an ester, known as a fat, oil or glyceride, is formed. Esters in which all three hydrogen atoms have been replaced are more common in fats and oils. They are called **triesters** of glycerol or **triglycerides**. An example is palm oil. The general structure of the triglycerides is shown in Figure 4.15. Note that there are three ester RCOO– groups in a triglyceride.

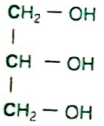


Fig 4.14 Glycerol structure.

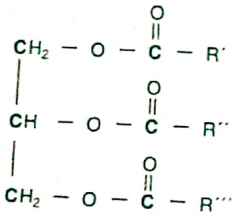


Fig 4.15 General formula for a triglyceride.

Both the large structure glycerides and the simple monoesters undergo the same chemical reactions as other esters because they contain the same functional group.

Fats and oils, as well as simple short chain esters, react with alkali to give the potassium or sodium salt of the long chain fatty acid – soap. Sodium hydroxide produces hard soaps while potassium hydroxide produces soft soaps. This is an important use of fats and oils.

Neutralisation and esterification

The esterification reaction of alkanoic acids and alkanols has some differences and some similarities with neutralisation reactions with inorganic bases and acids. The two processes are shown in the general equations:

acid + base → salt + water **neutralisation**

alkonoic acid + alkanol ⇌ ester + water **esterification**

Their similarities and differences are summarised in Table 4.5.

Table 4.5 Comparing neutralisation and esterification reactions

Neutralisation	Esterification
reaction is fast	reaction is slow
no catalyst involved	heat and catalyst involved
reaction is not reversible	reaction is reversible
water is a product; the hydrogen in it comes from the acid	water is a product; the hydrogen in it comes from the alkanol
the other product is an inorganic salt	the other product is an ester, an organic substance with a pleasant smell

ACTIVITY 4 To prepare the ester, ethyl ethanoate

Caution: Concentrated tetraoxosulphate(VI) acid is very corrosive and will damage skin and clothing on contact. Ethanol, ethanoic acid and ethyl ethanoate are flammable. Wear eye protection and avoid naked flames.

Your teacher will provide you with the following: two boiling tubes, measuring cylinder, ethanoic acid, ethanol, concentrated tetraoxosulphate(VI) acid, teat pipette, beaker, cold water.

1 a) Pour about 3 cm^3 each of ethanoic acid and ethanol into a boiling tube. Carefully add four drops of concentrated tetraoxosulphate(VI) acid.

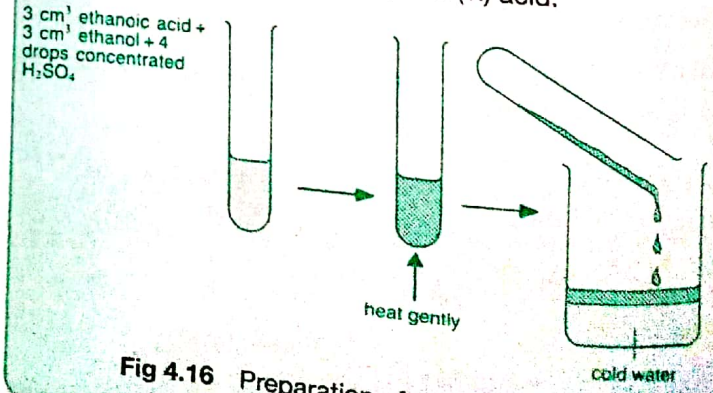


Fig 4.16 Preparation of ethyl ethanoate.

b) Pour about 3 cm^3 each of ethanoic acid and ethanol into another boiling tube. Do not add any acid to this.

2 Warm each tube gently over the Bunsen burner or in a water bath. Shake gently during the warming. Pour the hot contents into a beaker half full of water. Smell the products in the beaker. Describe the scent. Which reaction mixture gives a stronger scent, a or b?

3 a) Write a balanced equation for the reaction.
b) Name and write the structure of the ester formed.
c) What role did concentrated tetraoxosulphate(VI) acid play in this reaction?

4 a) Observe how many layers of liquid are in the beaker of the reaction mixture.
b) Which substance is the:
(i) lower layer (ii) upper layer?
c) (i) Which has a higher density, water or the ester?
(ii) Is the ester soluble in water?
(iii) Are the two liquids miscible or immiscible?
(iv) How might you obtain pure ethyl ethanoate from the mixture in the beaker?

5 Copy and complete the table below without carrying out the experiments.

Alkanoic acid	Alkanol	Ester (alkyl alkanoate)
benzoic acid	methanol	
methanoic acid	methanol	
propanoic acid	methanol	
ethanoic acid	butanol	

Petrochemicals

Petrochemicals are organic compounds obtained or derived from petroleum and natural gas. A major use of natural gas is as fuel. A **fuel** is a combustible substance that is obtained in commercial quantities and burned in oxygen or air to release useful heat or energy.

Natural gas may occur separately or together with petroleum. It is the gaseous part that is often referred to as the natural gas and the liquid portion petroleum. It is made up mainly of methane, CH_4 (85%), ethane, C_2H_6 (10%), propane and other hydrocarbons. Natural gas is processed and used as fuel.

About 90 per cent of refined petroleum is used as fuel and the remaining 10 per cent is used for the production of basic petrochemicals. The basic petrochemicals are in turn used for the production of a wide range of other chemicals or useful final products. Some of the final products, for example paints, detergents, plastics and drugs are used directly by consumers. Others are used further to manufacture basic human needs such as clothing and foods. Figure 4.17 shows some of the products manufactured from petrochemicals.

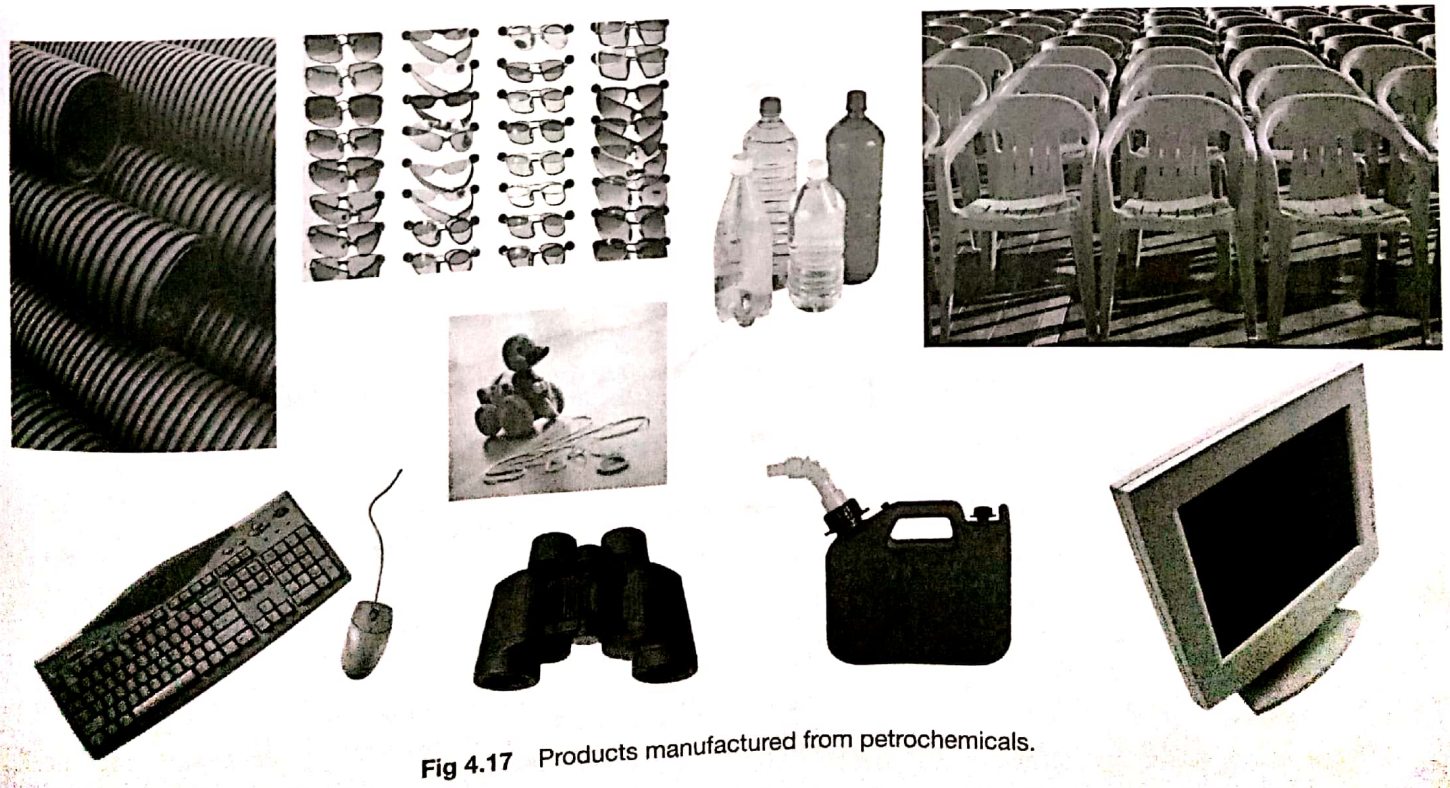


Fig 4.17 Products manufactured from petrochemicals.

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A very large amount of natural gas and petroleum are burned to provide energy but these human activities also release pollutant gases into the air. The main gas pollutants are carbon monoxide, carbon dioxide and sulphur(IV) oxide. The risks these gases bring into human and plant life and to the environment have been discussed in Year 1 Section 5, Unit 2.

Petroleum

Origin of crude petroleum

Petroleum is a mineral. It is a mixture of hydrocarbons found in the Earth's crust. It comes to the surface as crude oil or natural gas. Petroleum was produced over millions of years from the remains of marine animals and plants. The dead organic material is thought to have decomposed in a particular way under conditions of high temperature and pressure.

Petroleum is refined for use as petrochemicals and fuels.

Functions and uses of petroleum

Petroleum is a complex mixture of many hydrocarbons. This mixture can be separated into different parts by a process called **fractional distillation** or **fractionation**.

The fractions are separated according to their boiling points in towers and columns. The boiling point increases as the number of carbon atoms in the hydrocarbons increases. The hydrocarbons with the lowest boiling points pass furthest up the column before condensing. The hydrocarbons with the highest boiling points remain at the bottom of the column (Figure 4.18).

The fractional distillation of petroleum is carried out at a **refinery** such as Tema Oil Refinery (TOR). Each of the resulting fractions is used for a particular purpose:

- **Liquid petroleum gas** (LPG) contains such gases as propane and butane. Some of it is actually used by the refinery to provide the heat needed for fractional distillation.
- **Naphtha** is the fraction that provides petrol. Some also undergoes a process called **cracking**, which causes the complex, long-chain molecules in naphtha to break down into short-chain molecules. The products of cracking naphtha provide the starting chemicals for many industrial processes. This is sometimes called **feedstock**.
- **Kerosene** provides paraffin and the fuel for jet aeroplanes.

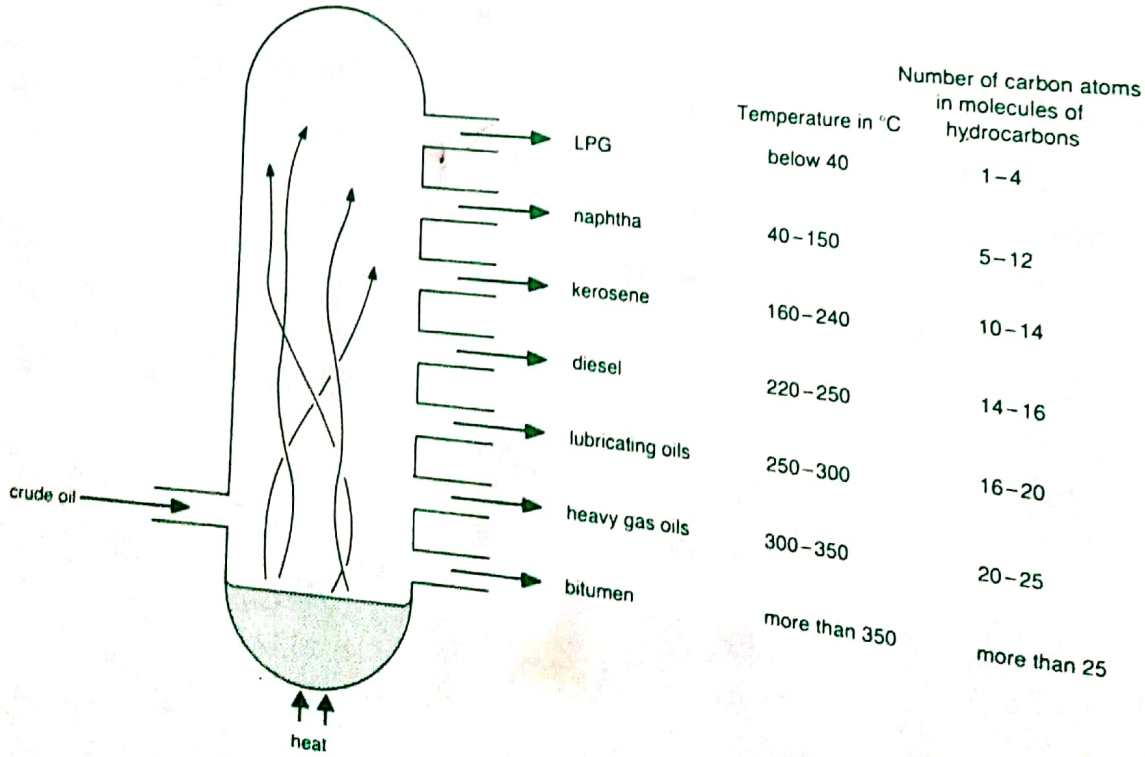


Fig 4.18 Fractions and uses of petroleum.

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- **Diesel** provides the fuel for the diesel engines of cars and lorries.
- **Lubricating oils** are used to lubricate machinery. This reduces friction and wear on the moving parts.
- **Heavy gas-oil** is used as a fuel oil in ships. Some undergoes cracking to produce more petrol and feedstock.
- The residue provides a material called **bitumen**. This is used to make roof felting and to surface roads.

PROJECT

1 *Work in groups* to discuss the problem of plastic waste disposal in your community.

2 Choose two local occupations, e.g. weaving, thread making, nursing seeds and so on, and design ways in which plastic waste can be reused.

Self check

For questions 1 to 4, choose the letter that refers to the correct option.

1 Carbon is referred to as tetravalent because it can:
I form only four single bonds in all its bond formations
II form a total of four bonds including single, double or triple bonds
III have four electrons in its outer shell
IV exist as charcoal.
A I
B II, III
C II
D II, III, IV

2 The correct formula of ethyl ethanoate is:
A $CH_3CH_2COOCH_3$
B $CH_3COOC_2H_5$
C CH_3CH_2COOH
D $CH_3CH_2COOC_2H_5$

3 Hydrocarbons are important because of their main uses as fuels and as:
A explosives
B a starting material for the manufacture of many other compounds
C manufacture of soap only
D food

4 Which of the following statements is/are not true?
I neutralisation is a fast reaction
II esterification is faster than neutralisation
III esterification reaction mixture is catalysed and heated
IV neutralisation produces a sweet smelling substance.
A I, III
B I only
C II, IV
D IV

5 Outline briefly an experiment you would carry out to determine whether a given piece of a substance contains organic compounds.

6 **a)** Why does carbon form a large number of compounds?
b) Explain why methane is unreactive but ethene and ethanol are reactive.

7 **a)** What is the meaning of:
(i) saturated hydrocarbon
(ii) unsaturated hydrocarbon?
b) (i) Give the general formula for alkenes and alkanes.
(ii) Write the molecular formula and name of one alkane and one alkene which have three carbon atoms each.
c) What would be observed when bromine is reacted with the two hydrocarbons named in b)(ii)?

8 **a)** Classify the following organic compounds into their family names, using their functional groups to help you:
CH_3COOH, palm oil, CH_3COOCH_3, $C_5H_{11}OH$, C_2H_2, CH_{12}, $CH_2(OH)CH(CH)CH_2(OH)$, C_4H_{10}.
b) Give one use each of:
(i) ethyne
(ii) butane and propane gas
(iii) kerosene.

9 **a)** Name two functional groups that can be found in fats or oils.
b) (i) How many ester groups would a triester fat contain?
(ii) What is soap?
(iii) Explain the differences (in structure and in their effects) between a soapy and a soapless detergent.

10 **a)** Name two naturally occurring:
(i) hydrocarbons
(ii) esters
(iii) acids.
b) Give one use of each substance named in (a).

11 Consider the following compounds:
C_2H_4, C_2H_6, C_3H_8, C_2H_5OH, CH_3COOH, CH_3COOCH_3.
Select the one which:
(i) will undergo polymerisation
(ii) is likely to have a pleasant smell
(iii) will liberate carbon dioxide with sodium hydrogen trioxocarbonate(IV)
(iv) may be used as a domestic fuel
(v) can decolourise bromine water
(vi) will produce CH_3COOCH_3 with CH_3OH.

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1 General principles of farm animal production

Learning objectives

After studying this unit, you should be able to:

1 outline the main activities involved in the production cycle of farm animals
2 practise ruminant production
3 practise non-ruminant production.

Background information

Farm animals are domestic animals raised on farms primarily for their products. They are often referred to as livestock and include **ruminants** (cattle, sheep and goats); **non-ruminants** (pigs, rabbits, guinea pigs and grasscutters); and poultry (fowls, guinea fowls, turkeys, ducks, geese and ostriches). Other kinds of farm animals are fish, horses and sometimes dogs.

In West Africa, farm animals are kept for various reasons including the following:

- food in the form of meat, milk and eggs
- clothing from wool, skin and hide
- farm power – soil tillage and transportation of farm produce
- income for farmers
- source of employment
- entertainment/recreation
- symbol of wealth and status in certain cultures.

Subsistence farming of livestock is still common in most West African villages and small towns. In bigger towns and cities, farm animals are kept as part of backyard farming. (See Figure 4.19.) In both cases, animals are often not properly cared for. In commercial livestock farming, however, activities usually follow laid down principles with the aim of giving the animals good care.

Principles of animal production are basic ideas or scientific rules which influence and guide the choice and use of all activities necessary to ensure healthy and optimum animal growth and development. The activities are the things livestock farmers do in the production cycle routinely or periodically to maximise productivity. In housing, for example, activities





Fig 4.19 Types of farming in West Africa **(a)** Subsistence farm; **(b)** Backyard farm.

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are aimed at the principle of giving rearing animals protection and good health.

Main activities involved in animal production

Selection of suitable breeds

Selection is the preferential choice of an animal for breeding purposes. Efficient and effective livestock production begins with a careful selection of a suitable breeding stock. These are a stock of animals with desirable qualities which can be passed on to their offspring through reproduction. Outlined below are some criteria used in the selection process.

Pedigree records

These are ancestral records of performance used in selection. This criterion is very useful when the animal is too young to exhibit performance characteristics, the desired trait is sex-linked or the trait is not expressed physically.

Individual performance records

Here the selection is based on the merits of individual animals in terms of characteristics such as feed conversion efficiency, birth weight, weaning weight and resistance to pests and diseases.

Appearance of animal

In using this criterion, desirable and observable physical features of the animal such as those listed below are used in the selection:

- good body conformation, for example the wedge shape of dairy cattle
- bright eyes
- strong straight legs
- a pair of well-developed testicles in male animals
- well-developed udder with functional teats in female animals
- absence of physical defects.

Progeny testing/performance

Selection of animals on the basis of this criterion depends on the performance of their offspring (progenies).

Sibling performance

Here selection is based on the performance of the siblings (brothers, sisters, half-brothers or half-sisters).

Choice of management system and housing

Good housing is an expensive but crucial consideration in the efficient and effective management of farm animals. Factors that influence good housing design include those outlined below.

Type of management system

Different types of management systems require different levels of housing. The **extensive system**, for example, requires little or no housing at all; the **semi-intensive system** requires some kind of simple housing; but elaborate housing is a vital integral feature of the **intensive system**. The farmer's choice of any of the aforementioned three management systems is influenced by factors such as housing cost, type and scale of enterprise, farm location and the skills of the farmer.

The essential conditions for good animal housing include the following:

- clean and dry floor or litter
- absence of flies in the house
- protection from pests, parasites and predators
- availability of feed and water troughs
- good ventilation
- good drainage system
- absence of sharp and pointed objects
- availability of footbath at the entrance of the house
- adequate floor space to check overcrowding of animals
- availability of essential equipment to meet the production needs of animals, for example egg laying nests, wallows, etc.
- good environmental sanitation.

Type of animal

Farm animals such as cattle, sheep, goats and pigs require solid, strong, well-equipped and well-ventilated housing units. Relatively smaller animals such as rabbits, poultry and guinea pigs require small housing spaces and do well in simple and sometimes temporary structures.

Type of product

Where animal products are delicate and prone to contamination, as in the case of eggs, milk and cheese, the housing should be designed so that it can be cleaned easily and regularly to ensure good sanitation and hygiene.

Breeding systems and care of the young

Breeding is the pairing or mating of male and female animals of a carefully selected breeding stock to

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produce offspring (young ones) with desirable qualities and in quantities considerable enough to increase the population of the animals.

Specific objectives of animal breeding are as follows:

- increase the genetic potential of the animals to produce more and, in the case of draught animals, to work better
- increase the quality of products
- improve resistance to diseases and pests
- improve fertility and fecundity
- improve tolerance to adverse environmental conditions
- accelerate maturity or increase growth rate.

Fecundity is the ability of a pregnant animal to carry and develop an embryo to foetus successfully.

Besides selection, other popular breeding systems or methods in use are **introduction** and **cross-breeding**.

Introduction

In this system, animals with desirable traits are sent from one place to another, or from one country to another where they did not previously exist. It is important to quarantine such animals to determine their health status before bringing them to the new environment.

Farmers should also ensure that conditions in the new farm or country are, or can be made, similar to those of the place of origin of the animals. This is to enable the animals to perform to the best of their potential. Normally the introduced animals are used to upgrade the performance of their local counterparts and not to replace them. Introduction is therefore also referred to as **upgrading**.

Cross-breeding

This is the mating of two animals of different breeds to produce offspring with increased vigour, referred to as **hybrid vigour** or **heterosis**. Better results are obtained with this system if the animals being mated are pure breeds or inbred lines.

Mating

In mating farm animals any of the three methods discussed below can be used.

- **Pasture mating** – the natural mating of male and female livestock while grazing on pasture. This indiscriminate and uncontrolled mating often results in the production of undesirable offspring. Pasture mating is common among livestock kept under the extensive and semi-intensive systems of livestock management.
- **Hand mating** – practised mainly under the intensive system and requires that female animals on heat are sent to a proven male animal for mating one after the other within a reasonable period. Mated female animals are often described as having been **serviced** by the males. Hand mating allows for the implementation of desired breeding programmes. With such programmes mating can be scheduled carefully so that the pregnant animal gives birth at a time when the environment is not too wet to affect the survival of the young animals and when there is enough food for the dam to convert into milk for its young.
- **Artificial insemination (AI)** – the deposition of carefully collected and chemically treated sperms of a proven male farm animal into the womb of its female counterparts on heat, using a syringe. The main advantage of AI is that the diluted semen (containing the sperms) can be widely used on a very large number of female animals. The introduction of new breeds of animals into a country is also safer (from the perspective of disease risk) and cheaper when frozen semen, rather than live animals, is imported. With this method, it is also possible to benefit from the use of good quality but physically weak or dead male animals. AI is not widely used in African countries, however, as it requires expert skills, relatively sophisticated and costly apparatus and a high degree of organisation for its successful practice.

Successful mating depends on detecting when a female animal is on **heat**, or in her **oestrus** cycle. When a female animal is on heat she is most ready to accept a male for mating. Such an animal will show the following signs:

- the vulva swells and becomes reddish in colour
- restlessness
- sniffing at other animals and attempting to mount them
- loss of appetite
- slimy discharge from the vulva
- making grunting noises.

Care of the young

Young animals are generally weak and vulnerable to disease and pest attacks. They also have small and weak

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digestive systems, which are sensitive to food. But it is at this time that they require the best of nutrition for growth and development and to resist disease and pest attacks. Young animals should therefore be given the best of care and attention with regard to nutrition and protection from pests, diseases and adverse environmental conditions.

Management practices

A management practice is the intelligent choice and use of production resources, techniques and methods aimed at increased productivity and profit. In the context of animal production the terms **management practice** and **husbandry practice** are used interchangeably, suggesting that they mean the same thing. Strictly speaking, however, 'husbandry' has to do with the direct care of farm animals in areas such as feeding, housing, handling and the control of pests, parasites and diseases. 'Management' embraces husbandry, but also includes decision making about, for example, correct stocking density, the best kind of food, and when and where to market animals and their products.

Management practices are aimed at:

- selecting good breeding stock and breeding programmes
- preventing and controlling pests and diseases
- providing adequate quality and appropriate nutrition to animals
- providing good housing
- ensuring good environmental sanitation
- using appropriate management systems.

Management practices may be carried out routinely, periodically or only once in the production cycle. Routine management practices include feeding, housing and cleaning. Periodic practices include culling, vaccination and dipping. Practices such as castration, identification, debeaking, dehorning and decombing are often carried out only once. Management practices such as feeding, control of diseases and pests, and record keeping are carried out in the production cycle of all farm animals; but others such as tail docking, dipping, castration, dehorning and decombing are animal specific.

Details of most of the above management practices are discussed under sections concerning specific farm animals, later in this unit.

Feeding

Food is a necessity for farm animals just as it is for humans. Well-fed farm animals are those that are given the right quantities of a balanced diet at the right times and under the right sanitary conditions. Good feeding creates animals that are able to:

- grow faster and bigger
- resist disease and pest attacks
- produce more good quality products
- reproduce better
- work better as they tend to have more energy.

In feeding young animals the following conditions should be met:

- access to colostrum – the first milk after birth – which is rich in minerals, vitamins and antibodies
- rations rich in high level proteins, vitamins and minerals
- provision of adequate clean and fresh water
- observance of good sanitary and hygienic conditions.

For all kinds, types and ages of farm animals, regular feeding of quality food is highly recommended. Quality food contains and supplies all the essential nutrients in the proportions required by the animals. Feeding at regular intervals ensures that the organs and systems of the animals are healthy and functional.

Finishing, processing and marketing of produce

Finishing farm animals entails giving them special care, particularly regarding nutrition, to improve their product and carcass qualities for higher market value.

In West Africa, both live animals and their processed products are sold in the farm or market. Processing of animal carcasses is often preceded by **pre-slaughter care**. Animals that are to be slaughtered should be starved and rested for about 24 hours. This is to empty their guts of faeces and undigested food which may contaminate the meat. It also relaxes them and reduces nervous excitement. There is also the opportunity for veterinary inspection of the animals to avoid the slaughter of sick animals.

Animals are normally slaughtered by cutting their throats using a sharp knife. Humane killing of animals involves stunning them with an electric shock, or a captive shot in the head, before cutting their throats.

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Stunning also reduces damage to the carcass that can be caused by the animal struggling before, during and after slaughter. It is good practice to thoroughly bleed slaughtered animals by hanging them upside down. Bleeding is essential for quality meat because carcasses with blood in their muscles or meat are less tasty and less attractive to consumers. Retained blood can also serve as a medium for bacterial growth and rotting of meat.

Activities involved in processing the carcass include flaying (removing the skin or hide) and evisceration (removing the intestines). Where meat is to be preserved it is frozen, dried, smoked, salted or canned for it to remain wholesome over a considerable period of storage.

Production of ruminants

Cattle, sheep and goats share some features. They all walk on **cloven** (divided) hooves, but by far the most prominent common feature is their ability to **chew the cud**. Chewing the cud, or **cudding**, is a more thorough chewing of a partially chewed, swallowed and regurgitated herbage in a relative state of relaxation and comfort.

Cattle, however, differ from both sheep and goats in a number of ways. Cattle are relatively more muscular and bigger than sheep and goats. Cattle also have a longer, hanging tail which ends in a 'bush' of hair.

Sheep are generally bigger than goats. Other distinguishing features of the two are summarised in Table 4.6.

Table 4.6 Differences between sheep and goats

Goats	Sheep
both the male and female can be bearded	only the adult male (ram) is bearded
during the mating season the male has a 'musky' or 'goaty' odour	no such odour
have short, usually erect, tails	have longer, hanging tails
legs have a built in 'shock absorber' system	no such features
heals have rubber-like pads	have glands between the toes

Cattle, sheep and goats are kept world-wide for their numerous economic and social contributions to humanity. In Ghana these ruminants are kept for social, subsistence and commercial purposes. Their production, however, is far below requirements in Ghana for animal protein. This under-production is attributable to poor management practices and inadequate year-round sources of feed and water.

Ruminant livestock, especially cattle, are kept mainly in the Northern Guinea savannah zones of West Africa. A small population is also kept on the coastal savannah plains. The transitional zones of Ghana have also served as home to an appreciable population of cattle. These areas are particularly suitable for livestock keeping because of the complete or near complete absence of tsetse flies (the causal agents of trypanosomiasis – see 'Diseases, pests and parasites'), and the relative availability of pasture for grazing. In the case of the Guinea savannah zones, the scarcity and erratic nature of rainfall in these areas makes them unsuitable for crop production. Thus, farmers tend to concentrate more on livestock production.

Cattle

Cattle belong to the *Bos* genus of the animal kingdom and the family Bovidae. Present-day cattle are descended from two species, *Bos taurus* of Europe and *Bos indicus* of Asia. Most tropical cattle belong to the *Bos indicus* species also known as the Zebus.

The sheer numbers of cattle world-wide is a reflection of their importance. There are estimated to be about 1.3 billion cattle in the world, India having the most – about 400 million, and there being about 200 million in Africa. Cattle are generally kept for meat (beef) and milk. Raw milk is consumed as a drink for energy, minerals and vitamins. Milk is also used to produce cheese, butter and ice cream. Cattle hides provide good quality leather for the manufacture of shoes, bags and jackets. The traditional use of cattle for work in most parts of West Africa is currently on the increase because the practice is relatively cost-effective and environmentally friendly. Figure 4.20 shows the external features of a cow.

Breeds and types

Both local and exotic breeds of cattle form the cattle population of West Africa. Through cross-breeding, hybrid cattle have also been produced (Figure 4.21). On the basis of the uses to which they are put and body configuration, cattle are classified into four types as follows:

- beef cattle, mainly producing meat
- dairy cattle, mainly producing milk
- dual-purpose cattle, producing both meat and milk

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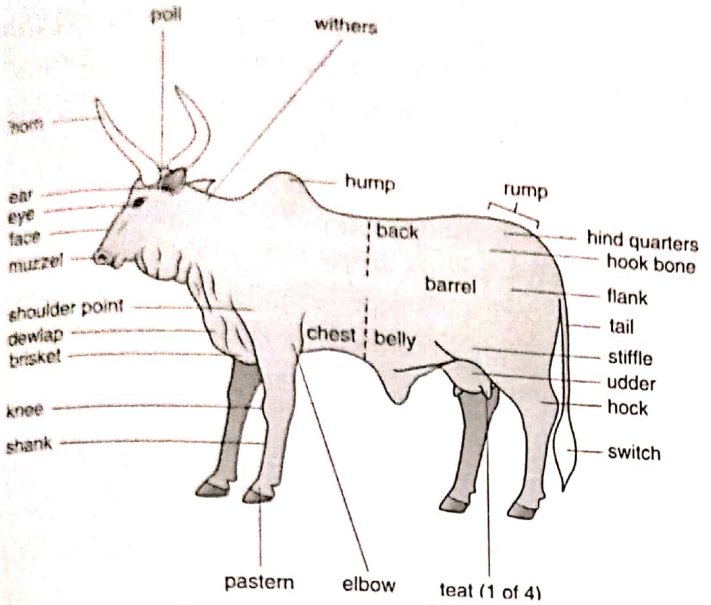


Fig 4.20 External features of a cow – White Fulani.

- work (or draught) cattle which are kept mainly for work.

Beef cattle

Generally beef cattle mature earlier than dairy cattle. They also produce less milk compared to dairy cattle. Meat from older cattle is called beef and meat from a calf less than three months old is veal.

Examples of exotic beef cattle include Aberdeen Angus, Brahma, Beef Friesian, Red Devon and Charolais. Local examples are N'dama and Muturu (collectively known as West African Shorthorns – WASH) and Zebu (Figure 4.21).

Zebus have a hump (enlarged muscle) on their shoulders. They have a long face and long or short, upright horns. Zebu cattle also have drooping ears, thin legs, and a dewlap (large fold of loose skin) hanging from the throat. White Fulani (Adamawa), Red Fulani, Sokoto Gudali and Red Bororo are examples of Zebu cattle. They are the main breed of cattle in West Africa because of their ability to tolerate warm and dry climates.

Dairy cattle

The main purpose of keeping dairy cattle is milk production. A good dairy cow should therefore be able to convert food into milk rather than into flesh or fat. As a result, dairy cattle generally have thin-fleshed bodies, fine skin and prominent bones. The whole body is, from a top view, wedge-shaped, allowing enough room for the udder and digestive organs.

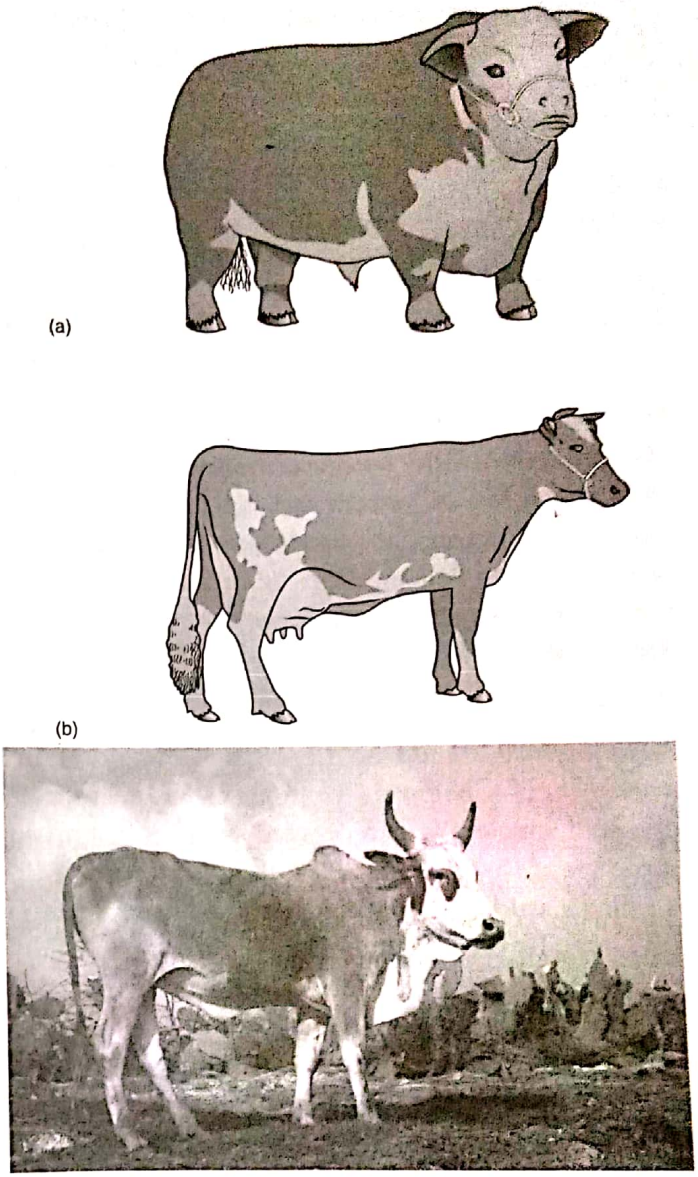


Fig 4.21 Different types of cattle **(a)** Aberdeen Angus bull (beef), **(b)** Jersey cow (dairy), **(c)** Zebu cow (dual-purpose).

Milk is synthesised and stored in the **udder**. During milking, pressure causes the milk to squirt out of the udder through large nipples called teats. Female beef cattle, which produce milk only for their calves, have relatively smaller udders. Most of the dairy cattle found in West Africa, except for a few Zebu, are exotic. They include Holstein-Friesian, Guernsey, Jersey (Figure 4.21), Brown Swiss and Ayrshire cattle.

Table 4.7 on page 460 lists the main differences between beef and dairy cattle.

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Table 4.7 Differences between beef cattle and dairy cattle

Beef cattle	Dairy cattle
heavy body, long broad back and thick muscles	slender body with prominent bones
body has a rectangular shape	body is wedge-shaped
generally humped	often humpless
small udder	large and well-developed udder
legs short and fleshy	legs relatively longer

Dual-purpose cattle

This type of cattle produces both milk and meat. However, they neither produce such large quantities of quality milk as true dairy cattle, nor such good meat as beef cattle. Red Poll and Dairy Shorthorn are examples of dual-purpose cattle, though they are not common in West Africa.

Breeding

A young bull should be 12–18 months old at first mating with a **heifer** (a young, sexually mature but unmated female cow). Heifers are ready for first mating at the age of 15–18 months. A bull selected for breeding is called a **stud bull**. The recommended mating ratio is 1:25–35. To preserve their vitality, young stud bulls should not exceed two matings per week, but older stud bulls may be used for four to five services per week. A heifer or cow has an oestrus cycle (period between one heat and another) of 21 days and a heat period of only 14–16 hours. Servicing heifers and cows during their heat periods has a high probability of resulting in pregnancy.

Gestation and calving

Heat or oestrus ceases with pregnancy which, in the cow, lasts for a period of approximately 290 days (about nine months). It is important to prevent constipation of the pregnant cow during this gestation period by feeding the cow sufficient roughage such as wheat bran.

When parturition (birth) is about to occur:

- the udder of the cow enlarges and the teats become waxy in appearance
- the belly becomes distended and drops
- the vulva becomes relaxed
- there is frequent urination
- the animal may separate itself from the rest of the herd.

Before calving the cow should be provided with clean and comfortable bedding in the calving pen, and lots of fresh, clean water. Normally a cow calves in a standing position and without any difficulty. A normal calving takes 30–40 minutes after the beginning of labour pains. The afterbirth (placenta) is expelled six to 24 hours after calving. In a few cases it drops within two hours. Gentle traction by an experienced attendant or a veterinary officer is all that is required to remove it if it delays beyond 24 hours.

Calf rearing

Soon after calving, the dam should be allowed to lick the calf. This often helps to remove mucus and membranes from the mouth and nose of the calf. It also stimulates blood circulation to keep the calf warm. If the dam is unable to lick its calf due to the exhaustion of parturition, the mucus and membranes should be removed by a clean, experienced hand. It is also important to tie a string on the navel of the newly born calf some 20 cm below its belly for the portion below the string to drop in a few days. Alternatively, the navel may be cut at the same position and treated with iodine to prevent diseases and to hasten healing.

The calf must be allowed access to the mother's colostrum in the first four days after calving. It contains antibodies and hormones and is particularly rich in proteins, minerals and vitamin A. As a result it strengthens and protects the calf from diseases by giving it natural passive immunity. This way, the calf is given a sound start in life and stimulated to grow and develop rapidly. Colostrum also has a laxative effect on the calf. It tones up its intestines and helps to prevent constipation.

Calves should be reared with great care, especially during the first six months of their lives. During this period their digestive systems are still developing and they cannot digest and utilise fibre. They should therefore be allowed to continue suckling their mother's milk. They should, however, be encouraged to learn to nibble at concentrate or good quality hay or silage in preparation for pasture grazing or zero grazing after weaning at the age of six to nine months.

After weaning, the calves should be grazed on pasture that is free from old, hard and fibrous grasses. Limiting the grazing time helps prevent calf constipation. It is also essential to protect them from tick infestation and fly worries.

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Good care is needed in calf rearing, because the calf of today is the breeding stock of tomorrow and the source that will yield future income.

Goats

Goats are found in most parts of the world including rugged and mountainous areas. This is because of their inherent ability to resist most pests and diseases, adapt to adverse environmental conditions and to survive on marginal vegetation.

Goats are economically important because they produce good quality meat, milk and silky wool. Goat's milk, for example, ranks third, world-wide, only to cow's and buffalo's milk. It has a higher vitamin A content than cow's milk but a lower content of vitamins B and C. Goat's milk is easier to digest than cow's milk, so it is an important source of food for babies, the aged and the sick. Nubian, Saanan and Toggenburg are the best breeds of goat for milk production, and the Angora breed is known for the production of silky wool.

In Ghana, goats are kept mainly for meat. Examples of goats reared for this purpose are Sokoto Red, Bornu, and the long-legged Sahelian goat. Others are the West African Dwarf (Figure 4.22) and Kano Brown.



Fig 4.22 West African Dwarf – a common breed of goat.

Breeding

The **gimmer** (young female goat) is sexually mature for first mating when it is about six months old. However, it is advisable to delay this first mating until the gimmer is 12–18 months old. It is also recommended that the **billy** (male) goat is kept until one to two years old before it is used for first mating. The mating ratio for hand mating is 1:50, and for pasture mating 1:40.

The pregnant **nanny** (female) goat **kids** (gives birth) after 150 days gestation. **Kids** (offspring) should be allowed to suckle colostrum to give them a good start in life. They should also be provided with mineral sources, such as fresh earth, in suitable containers. When two to three weeks old, the kids should be introduced to good quality silage, hay, concentrate and fresh forage. They can benefit from pasture grazing at three months old when they are to be weaned. Weaners are identified and males not meant for breeding are castrated.

Management of goats

Goats are browsing animals. They will browse any plants available and so they often destroy crops. This requires that goats are properly managed.

In rural areas of Ghana where most goats are found, they are kept for subsistence on free range. They can be seen roaming the village unattended, eating any suitable vegetation and other foods including cassava and plantain peel. In the evening, they return to makeshift pens provided by their owners.

In urban areas, goat owners, by law, confine their goats in small pens in their backyards. The goats are fed on the peelings of cassava and plantain, food leftovers and fresh forage or shrub. Those who let their goats out to browse on vegetation around their homes either tether them, or ensure that they are properly attended to prevent them from causing damage to planted backyard crops or other vegetation. The provision of fresh clean water is an essential aspect of any good management system.

Sheep

Sheep are widely kept for their meat, milk, wool and skin. In West Africa farmers rear them mainly for their meat (mutton). Most of the sheep reared in Ghana can be found in rural areas. The most common sheep management system in these areas is the extensive system. Farmers who practise the system are mostly subsistence farmers. In some cases large flocks of sheep are kept using the semi-intensive system.

Some city dwellers have also found the rearing of sheep in their backyard to be a reliable source of animal protein and sometimes income. Sheep owners in the city often tether their sheep in the neighbourhood during the day to graze. At night the sheep are sheltered in simple pens in the backyard. Rearing sheep in total

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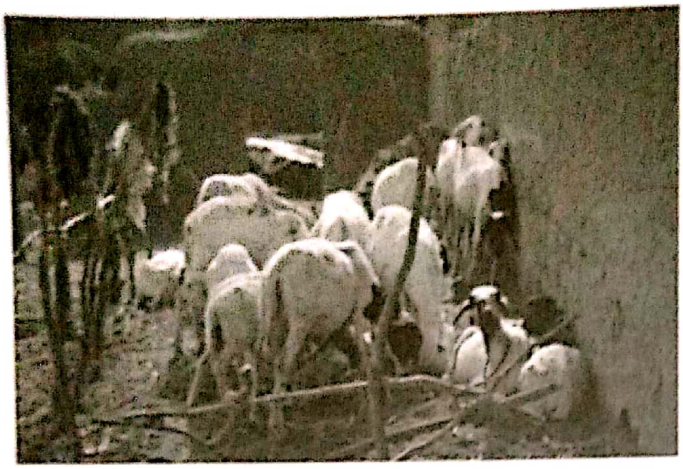


Fig 4.23 A herd of Fulani sheep.

confinement is rare in Ghana except on some research farms.

Breeds

Classification of sheep into breeds is based on the following:

- body size and shape
- tail size and coat characteristics
- length of legs (short or long)
- function/use (meat, milk or wool).

For example, among the African breeds of sheep are the African Long-legged, West African Dwarf, East African Fat-tailed and Fulani (Figure 4.23). Many variations of local sheep belong to the Fulani breed including the Ouda (the most numerous), Yankasa, Ornu and Fellata. The hybrid sheep called Nungua Blackhead is also a member of the Fulani breed.

Ouda

These sheep are mostly found in the northern parts of West Africa. They have short hair and a convex face. Their ears are long and pendulous. They are generally white in colour from the tail to the middle of the body, then either black or brown from this point to the head. Ouda are tall, standing at about 65 cm at the shoulder, and they weigh about 40 kg. Most of them have dewlaps.

Yankasa

Yankasa have short hair, a short neck and non-pendulous ears. They are white in colour with black patches on the face especially around the eye. Yankasa are generally resistant to trypanosomiasis.

West African Dwarf

This breed of sheep is short and small. Their ears are narrow, short and erect. The ram has curved horns but the ewe is **polled** (hornless). They may be white, black or a mixture of colours. They are common among subsistence sheep farmers. They are the breed most resistant to trypanosomiasis.

Nungua Blackhead

This breed of sheep was developed at the University of Ghana Animal Research Farm at Nungua. It is a hybrid of a cross between the West African Dwarf and the Blackhead Persian breed from South Africa. The body colour is usually white and the head is always black.

Breeding

Both pasture mating and hand mating are practised in the breeding of sheep. The young ram (male) and the gimmer (young ewe) should be 10–18 months and 8–18 months old respectively at first mating. A breeding ratio of 1:20–25 is recommended. Ewes have an oestrus cycle of 17 days and a heat period of 18–24 hours. Flushing ewes (feeding good quality pasture, silage or hay) two weeks before mating leads to multiple births. Pregnant ewes **lamb** (give birth) after about 150 days of gestation.

Lambs should have ready access to colostrum and be carefully reared until weaning at six months. Lambs that will not be used for breeding should be castrated when they are one to two months old. They are best castrated using the elastrator method (see 'Routine husbandry practices').

Management systems

Cattle, sheep and goats are all managed under three main systems: extensive, semi-intensive and intensive systems.

Extensive system

This is the traditional and therefore the most common system of managing ruminant livestock in West Africa. The cattle, sheep or goats are grazed on pasture during the day and provided with shelter against theft and adverse weather conditions at night. In the case of cattle they are driven into kraals at night after grazing in the day (Figure 4.24).

Most kraals are not roofed. They have only a few facilities for drinking water, supplementary feeding and animal handling. Often, lactating animals are milked in

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Fig 4.24 A cattle kraal.

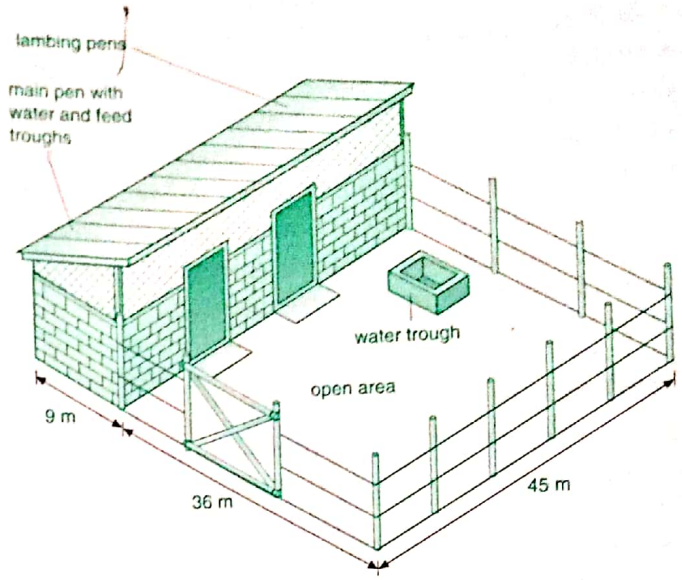


Fig 4.25 A well-constructed pen for sheep.

the kraal and calves are encouraged to suckle their dam's milk before the herd is allowed out on pasture.

Pastures grazed under this system are large areas of cheap, natural grassland. From these the grazing animals are required to derive their food nutrients for maintenance and production. The extensive system is practised mainly in areas where natural pastures abound. Grazing is done either continuously or in rotation. Continuous grazing of pasture requires that animals are moved from exhausted pastures to fresh ones. When herdsmen move with large herds of cattle in search of pasture and water, the practice is referred as **nomadism**. The mostly Fulani herdsmen in West Africa, called nomads, often move along with their water gerbas (water bags made from animal skin) and cooking gear. They depend mainly on cow's milk for food and income. Whilst on the move, nomads communicate with their animals by voice and by tapping them with walking sticks.

This system requires little or no capital investment in housing and feeding structures. Animals often have access to a wider range of herbage, thus meeting their nutritional requirements fairly adequately. Unfortunately, however, the animals are exposed to rain, cold and heat. There is also the danger of being attacked by natural predators such as larger carnivorous animals, of being bitten by snakes or of being stolen. Animals kept under this system are also exposed to disease and pest attack. There is a lot of indiscriminate mating among the stock resulting in generations of poor vigour and performance. Other disadvantages of the system include difficulties in record keeping and animals going astray to destroy crops on farms around homesteads.

Intensive system

This system is characterised by the total confinement of the livestock to well-sited and elaborate housing units called pens. The pens or sheds have concrete walls and floors with inlets near the roof (asbestos or iron sheets) for ventilation. The floors have channels for urine and dung, which facilitates cleaning of the pens and helps maintain high standards of sanitation. The pens are also provided with feeding and water troughs and hay racks. Modern pens have separate areas for lambing or calving, for the breeding male and for the isolation of sick animals (Figure 4.25).

Though the intensive system of managing livestock requires heavy financial investment in housing, it has been found to be ideal for the production of healthy and high quality livestock. This is because the animals are well fed, and are also protected from rain, heat and strong winds, pests and diseases, predators and theft. Zero grazing or the cut and carry system is the main grazing system used.

Semi-intensive system

In this system livestock are housed in walled and roofed pens at night and during adverse weather conditions. During the day the animals are allowed out to graze improved pastures in rotation (rotational grazing or paddocking – see 'Feeding and grazing practices'). While indoors, the animals are given supplementary feed, and husbandry practices such as castration, periodic dipping and deworming, dehorning and identification are carried out.

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In West Africa, the semi-intensive system is practised for cattle mainly on research and university farms. City dwellers who keep sheep and goats have also found this system suitable. They keep their sheep and goats in pens in their backyards at night. During the day, sheep and goats are seen tethered in the neighbourhood to allow them limited grazing. Tethering prevents sheep and goats from destroying backyard crops and neighbours' property.

Feeding and grazing practices

Under modern methods of cattle husbandry, cattle are fed on improved, permanent and well-maintained pastures. Pasture is a piece of land with grasses or a grass–legume mixture of high nutritive value for the use of grazing livestock. It may be natural or artificial (cultivated) grassland. Cattle are sometimes zero grazed on forage, or on hay and silage in areas and at seasons when herbage is scarce. This is particularly so when the cattle are in total confinement under an intensive system.

In the wet season cattle obtain a large proportion of their water requirements as components of fresh grasses and legumes during grazing. In the dry season sufficient fresh and clean water should always be provided for them. It is also advisable to provide them with a salt lick to provide essential minerals vital for healthy growth and production.

Malnutrition should be avoided in the feeding of cattle and all other farm animals. Malnutrition is mainly the result of inadequate quality and quantity of rations. It is avoided by feeding animals on rations considered balanced and adequate for their class, type, age and condition. For example, just before parturition, pregnant cows are given a special ration known as steaming-up ration. This is rich in proteins and vitamins and helps to induce increased activity in the cow and its fetus. Similarly, giving cows, ewes or nanny goats extra rich food before mating increases their pregnancy rates. The feeding of this extra food is known as **flushing**.

Grazing systems

Whether natural or artificial, pastures are grazed using one or more of the following systems:

Continuous grazing

This system is practised mainly under the extensive system of livestock management. The stock remains on the same pasture for prolonged periods. It is common on natural pastures of tropical grassland where fencing is economically impractical.

The use of the pasture follows the same pattern each year, and the success of the system depends on the **stocking rate** (the number of grazing livestock per given area of pasture). Over stocking of pasture reduces the availability of good forage while under stocking leads to the wastage of a lot of forage. The problem is solved by not keeping a constant number of livestock throughout the grazing season or year, but to stock set the pasture. This involves varying the number of livestock on pasture according to the availability of herbage as the season varies from wet to dry.

Continuous grazing is inexpensive because it needs only a low management input. Only minimum labour, maintenance and provision of drinking water are required. The pasture does not require fencing.

On the other hand, the system does not lend itself easily to the assessment of pasture growth to match the stock requirements. It is also characterised by a high build up of both ectoparasites and endoparasites such as ticks and worms respectively. Also, because the pasture is continuously grazed, fodder conservation is not possible.

Rotational grazing

This system, sometimes referred to as paddocking, is an intensive system of grazing practised basically on improved permanent pastures. The essential feature of the system include a field of pasture broken up by fencing into six to eight blocks, known as **paddocks**. Grazing animals are rotated from one paddock to another for a period of time ranging from three to seven days, depending on the stocking rate and the season (wet or dry). For example, in the wet season, when pasture grow quickly, higher stocking rates and longer paddock grazing periods are feasible. Paddocking (movement of the stock from one paddock to another) ensures the animals are moved back to already grazed paddocks after a period of pasture regrowth.

With rotational grazing, high yields of pasture are obtained. Pasture is also uniformly grazed leading to a more efficient utilisation of herbage. The system also provides room for the control of livestock pests, parasites and diseases. Forage conservation is possible and simplified. This is because one or two paddocks can be set aside to be harvested as hay or silage. However, the cost of fencing and provision of water drinking points is

the paddocks make this system more expensive compared to continuous grazing. Also, pasture is normally soiled and fouled during grazing.

Zero grazing

Zero grazing, variously referred to as **soilage**, **mechanical grazing**, or **cut and carry system**, involves the cutting and carriage of forage to livestock in confinement. The forage, which may be grass, legume or even shrub, is normally fresh and green. Zero grazing also includes the feeding of conserved forage such as hay and silage to confined livestock. Conserved forage in any form is referred to as **fodder**.

The main advantage of zero grazing is that there is a more efficient utilisation of forage or fodder resulting in higher production. There is also better control of pests, parasites and diseases, particularly bloat (a digestive disorder). Bloat is controlled because forage is often allowed to wilt before being fed to the animals. The lack of need for fencing or the provision of drinking water points in the pasture make the system less expensive.

Disadvantages include the cost of cutting and transporting forage to the confined animals, the need to provide bedding for the animals and the problems of manure disposal.

Important forage grasses in West Africa include guinea grass (*Panicum maximum*), giant star grass (*Cynodon plectostachus*) and gamba grass (*Andropogon gayanus*). Centro (*Centrosema pubescens*), tropical kudzu (*Pueraria phaseoloides*) and stylo (*Stylosanthes gracilis*) are among the important forage legumes.

Preparation of hay and silage

Hay is a dry forage conserved for use by livestock at a future date. Silage is a fresh green forage preserved by partial fermentation (the terms conserve and preserve are interchangeable in this context).

Hay

Hay crops are mainly legumes and grasses including cereal crops such as maize and sorghum. Hay is best prepared in the dry season when there is sufficient sunlight to cure the swath (a collection of cut grass/legume).

The whole process begins with the harvesting of the hay crop at the early flowering stage. At this stage the crop is leafy, more nutritious, less fibrous and has a lower water content. After removing weeds and other foreign materials from the swath, it is left under the sun to dry to a moisture content of about 20 per cent. Periodic turning of the swath ensures faster and uniform drying. The well-cured hay is then gathered, baled and stored on stacks and under shade in a dry and well-ventilated room or shed.

Standing hay or in-field hay is conserved by allowing the crop to dry while 'standing' in the field. While it is easier and cheaper to prepare standing hay, it is also risky because of the possibility of the crop being consumed in rampant West African bush fires.

A well-prepared hay must have the following qualities:

- slightly green colour
- high leaf to stem ratio (must be leafy)
- nutritious and palatable to livestock
- less fibrous and easily digestible
- low moisture content (15–25 per cent)
- no dust or mould
- free from weeds and other foreign materials such as stones
- ability to store for a long period without deterioration.

Silage

Silage preparation is technically referred to as **ensiling**. Most hay crops are also suitable for ensiling. During this process the forage crop is preserved in a green state by acids produced as a result of anaerobic fermentation of sugars present in the fodder.

Ensiling involves cutting, chopping and compacting the silage crop within a period usually not more than two to three days. Just as in hay preparation, silage preparation starts with the harvesting of the silage crop at the flowering stage. But this time the swath is chopped into pieces and immediately hauled from the field and emptied into either a pit or tower silo. The material is then compacted while in the silo to exclude air using a heavy tractor or any other suitable means. The silo is then soil-sealed and covered with supported tarpaulin to protect it from rain and sun.

The exclusion of air helps to kill all aerobic bacteria in the fodder that would otherwise cause its decay and deterioration. Further bacterial action is then taken over by anaerobic bacteria which, in a partial fermentation, reduce the sugars (carbohydrates) into organic acids such as lactic acid. This condition also favours enzymic actions in the leaves, resulting in a slight breakdown of proteins into amino acids, and in a

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further breakdown of the amino acids into volatile free acids and ammonia gas. The cumulative effect of these biochemical processes during the fermentation is the reduction of the pH of the silage medium to about 4.5, which is low enough to stop any further bacterial and/or enzymic activities. This way the silage is preserved at a moisture content of about 70–80 per cent until use.

A good quality silage should be green in colour, leafy and free from moulds and offensive odour. In West Africa, the use of silage is more widespread than the use of hay for the following reasons:

- ensiling is cheaper, quicker and less laborious
- the process is less at risk from weather and fire than hay-making
- silage retains a higher proportion of leaves, water and nutrients than hay
- silage is more palatable to livestock than hay because of its characteristic sweet aroma
- silage has a laxative effect and thus helps prevent constipation in livestock.

The differences between silage and hay are summarised in Table 4.8.

Table 4.8 Differences between silage and hay

Silage	Hay
high moisture content (about 70%)	low moisture content (about 20%)
highly acidic	less acidic
highly palatable	less palatable
strong aroma	weak aroma
slightly wet and green	dry and dusty, not green
low vitamin D content	high vitamin D content
has a laxative effect	no laxative effect

The overall objective of the conservation of fodder, either as hay or silage, is to prevent herbage damage, wastage or loss in the wet season. A logical consequence of this is the availability of enough fodder to feed livestock during the dry season when forage crops are scarce.

Diseases, pests and parasites

Diseases

Most of the diseases that infect cattle are also common among sheep and goats. The most common are described in Tables 4.9 and 4.14.

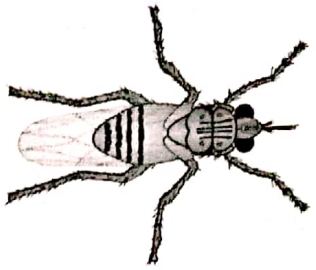


Fig 4.26 Tsetse fly.

Pests

The main pests are tsetse flies and mosquitoes. The **tsetse fly** (Figure 4.26) is common in the humid parts of Africa south of the Sahara; this zone includes West Africa. The tsetse fly has two wings and carries parasites called trypanosomes, the causal agents of the trypanosomiasis disease. This disease is known as nagana in cattle and sleeping sickness in man. Tsetse flies are commonly found along lake shores and river banks. There are about 20 species of tsetse fly of which *Glossina* spp. are the most dangerous.

Wild animals such as buffalos and giraffes are the carriers of trypanosomes. Domestic animals and humans become infected when bitten by the flies. Thus the trypanosome has two hosts – wild or domestic animals and the tsetse fly.

When either livestock or humans are bitten by trypanosome-infested tsetse flies, the trypanosomes invade and multiply in the bloodstream of their victims. They also invade the eye, brain and skin tissues. In most cases, the disease begins with cold-like symptoms of headache and fever. Severe cases, involving the attack of the nervous system, result in uncontrollable prolonged sleep, coma and death.

The disease is controlled by removing bushes and undergrowth along streams to reduce the population of tsetse flies. Thorough spraying of the infested farm vicinity with insecticides has also proved successful. Spraying livestock with insect repellents helps them avoid tsetse fly bites. Recommended prophylactics (preventative treatments) also control the disease. Other control efforts include the use of gamma rays to make male tsetse flies sterile in order to prevent them from reproducing.

Early detection of the disease in both humans and livestock is important because prompt treatment eliminates the pests and prevents permanent breakdown of the central nervous system.

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Table 4.9 Common diseases of cattle, sheep and goats

Disease	Transmission	Symptoms	Prevention
Anthrax – an extremely dangerous and deadly disease which infects both livestock and humans. It can pass from animals to humans. It is caused by a bacterium called *Bacillus anthracis*.	The causal bacteria are transmitted through contaminated water and pasture. They may also be picked up from the soil. Injuries resulting in wounds are possible sources of entry for the bacteria.	Symptoms of anthrax include high fever, and swellings in the neck, lower abdomen and genitals. The infected animal staggers and dies suddenly. By far the surest symptom of the disease is the oozing of blackened bloody discharge from all the openings of the animals soon after death. The discharged blood does not clot.	This deadly disease has no effective treatment, but isolating and vaccinating sick animals early enough sometimes proves successful. The carcasses of animals that die of anthrax should be immediately burnt or buried deeply to prevent its spread. All equipment and the entire vicinity should be disinfected.
Rinderpest (cattle plague) – a contagious viral disease which affects mainly cattle and sometimes pigs.	Transmission is through contact between sick and healthy animals and through inhalation.	Infected animals become feverish, developing high body temperatures. The animal develops large ulcers in the mouth and on the tongue. Other symptoms are running eyes and nostrils and blood-stained diarrhoea. Sometimes the sick animal experiences muscular twisting and arching of the backbone.	Quarantine and immunisation of cattle are the known methods of prevention. Once infected the animal should be isolated and vaccinated, but it may not be helpful.
Foot and mouth disease – a contagious viral disease.	It is transmitted through infected materials such as milk, urine, water and feed.	The sick animal has high fever with the body temperature rising to as high as 40°C or more. It has blisters in and around the mouth and hoofs. These blisters result in lameness and the inability to eat. Profuse salivation, with saliva hanging in strings is seen.	Foot and mouth is prevented through strict quarantine and vaccination. All ruminant livestock (and pigs) can be infected. Infected animals must be slaughtered and the bodies burned or buried in lime pits.
Brucellosis – an infectious disease also known as contagious abortion or Bang's disease. It is caused by the bacterium *Brucella abortus*. Among livestock, cattle are the main victims of the disease. In sheep and goats brucellosis is caused by *Brucella melitensis*. When this infection is transmitted to humans it causes undulant fever.	Among livestock, brucellosis is transmitted through mating and grazing of contaminated pasture. The ingestion of contaminated food, water or milk is another mode of transmission. Vaginal discharges, faeces and aborted fetuses are the main sources of contamination of paddocks and food. Infected milk transfers the disease to humans.	It normally affects the lymph glands, udders and the reproductive organs of the infected animal. It is thus a major cause of reproductive failure in domestic animals, causing abortion in the females and sterility in the males. The sterility in male animals is due to orchitis (inflammation of the testes) and epididymitis (inflammation of the epididymis).	Vaccinating animals 3–6 months old with Brucella strain 19; and heifers, cows and bulls with Brucella strain 45/20 helps prevent the disease. Another preventative measure is to bury aborted fetuses and kill infected animals. The disease is difficult to treat.

Parasites

An **endoparasite** lives in and derives nutrition from its host. An **ectoparasite** lives on the outside of an animal. Worms (roundworms, tapeworms, liver flukes, etc.) are the main endoparasites of livestock. Ectoparasites include ticks, lice and fleas. A tick is a tiny blood-sucking animal that is related to mites and scorpions. Ticks normally hide in the ears, legs and between the

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Table 4.9 Common diseases of cattle, sheep and goats (*continued*)

Disease	Transmission	Symptoms	Prevention
PPR (peste des petits ruminants) – a fast-spreading, severe disease, caused by a virus. It is found only in goats and sheep, and is less serious in sheep.	Transmission is through close contact. Fine infective droplets are released into the air from sick animals, particularly when they cough and sneeze. Infectious materials, including faeces, may also contaminate water and feed troughs and bedding.	Its symptoms are depression, fever, diarrhoea, discharge from the eyes and nose and sores in the mouth. Infected animals may die after one week.	Quarantine and focused vaccination are used to control PPR outbreaks. Immunisation in high-risk populations can also be used to prevent PPR.
Joint-ill (navel-ill) – a disease of young lambs. It is caused by many types of bacteria.	The bacteria enter the young lambs through a wound or the navel.	Animals suffering from Joint-ill have swollen leg joints. This is usually followed by death.	This disease can be prevented by ensuring that pregnant ewes lamb in very clean environments. Treating the navel of newly born lambs with iodine and any other suitable antiseptic also helps to prevent Joint-ill.
Mastitis – a disease condition of the udder of cows, ewes, sows, and other domestic animals. It may be caused by both bacteria and fungi. Bacteria of the *streptococcus* spp. are, however, the main causal agents.	The bacteria are transmitted through the teat canals or wounds on the udder. Exposure of the udder to wet surfaces and cold can also cause mastitis.	The disease is recognised by an inflamed udder which is hard to touch. Milk produced by the udder is yellowish in colour and may contain clots. The udder sometimes develops sores on account of which calves may not be allowed to suckle.	Mastitis is prevented by general good sanitation such as the disinfection of the teat cups of milking machines. It is treated with antibiotics such as streptomycin and tetracycline.
Bloat – a disease of ruminants caused by the accumulation of frothy materials and gases, especially methane gas, produced as a result of the fermentation of starchy forage and large quantities of unfamiliar high-energy foods. Proteinaceous grains low in roughage also cause bloat. The rumen becomes distended, reducing the internal cavities of the animal.	Not applicable.	The symptoms are laboured breathing and staggering, profuse salivation and the animals lying on the right side showing a swollen left side up.	Bloat can be prevented easily by grazing animals on fresh pasture for short periods, providing enough roughage such as hay and by zero grazing. A bloated animal is treated using a trocher and cannula to puncture the rumen on the swollen left side. After puncturing, the trocher is withdrawn, leaving the cannula for the gas to escape through. Alternatively, the gas can escape through a clean rubber tube by inserting it through the oesophagus to the entrance of the rumen.

hoofs of their hosts. Many ticks that attack animals also attack humans. The bites of some ticks are poisonous and can cause human paralysis and death. In domestic animals they feed on the blood causing body irritation, anaemia, emaciation and death in some cases. They also transmit heartwater, Redwater and anaplasmosis diseases of livestock.

Hand-picking ticks for destruction, dipping, general cleaning and rotational grazing are all effective measures of tick control. Year 3, Section 2, Unit 1 gives a more detailed account of ticks and other parasites and pests of livestock.

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ACTIVITY 1 Visiting a commercial or a research livestock farm

1 Visit a good livestock farm where cattle, sheep and goats are kept on a large scale.

2 Observe and identify the breeds of cattle, sheep and goats.

3 Record the observable differences between beef and dairy cattle (if both are available on the farm).

4 Ask the farmer or the stockman questions on:
   a) the system(s) of management in use on the farm
   b) the grazing system(s) being used
   c) the uses to which the livestock are put
   d) the way pests, parasites and disease are controlled.

   Reasons for choice of management or grazing systems should also be sought.

5 With the help of your teacher or the stockman:
   a) identify available forage grasses and legumes
   b) observe hay and silage for visible differences between them
   c) locate and describe a silage pit or tower.

6 *Work in groups* to discuss your visit back at school and write a group report.

Production of non-ruminants

Poultry production

The term poultry generally refers to all domestic birds kept mainly for their meat or eggs. Kinds of poultry include fowl (chickens), ducks, turkeys and guinea fowl. The less common kinds are ostriches, pigeons and swans. The term is, however, now often taken to mean fowl because they are the most widely reared birds as they are more useful and profitable to poultry farmers than the other types. Consequently, most of the discussion on poultry in this text will be on fowl.

All of today's breeds of fowl have been derived from *Gallus gallus*, a native of north-west India and south China. Fowl are commonly allowed to roam freely in the farmyard, backyard or village, pecking up scraps of grains, insects and green foliage, and laying their eggs wherever they fancy. This **free range** system of poultry keeping is still being practised in most rural areas in West Africa.

Modern developments in production have revolutionised the poultry industry into a lucrative occupation for commercial poultry farmers. This revolutionary spirit caught up with Ghanaian farmers in the 1970s when the then Government of Ghana launched a vigorous campaign of agricultural development with emphasis on backyard farming. Many people went into poultry production and made fortunes out of it. Poultry keeping is still a paying occupation for most Ghanaians, especially women.

Poultry are kept for several reasons including the following:

- source of nutritious food (meat and eggs)
- source of income for farmers
- manure for fish ponds and vegetable gardens
- employment for people
- feathers for decoration, filling pillows, and for processing into fertilisers and feed for farm animals.

Breeds of fowl

A breed of fowl is a class of birds which are believed to have descended from a common ancestor and are very much alike in many respects, including body shape, size and plumage (feather) colour. Both indigenous (local) and exotic (foreign) breeds are found in the poultry industry in Ghana. While local breeds are mostly reared for subsistence, the exotic breeds constitute the bulk of fowl kept for commercial purposes (Figure 4.27).

Indigenous (local) breeds

These are breeds that originated in Africa and have changed little over time. They are generally small in size and have tough flesh. Their plumage varies in colour from white to black, including multi-coloured mixtures. They have poor growth rates. Hens have a low egg-laying capacity (20 to 30 eggs a year) and are often **broody** (sit on their eggs). They are, however, resistant to diseases and adverse tropical weather conditions, and have great foraging ability.

Exotic (foreign) breeds

These are breeds that have been introduced into Africa from other countries. They have distinct colours, depending on the breed. They are better than the local breeds for the following reasons:

- faster growth rates
- more tender flesh
- larger body size
- hens lay many eggs (200 to 270 a year).

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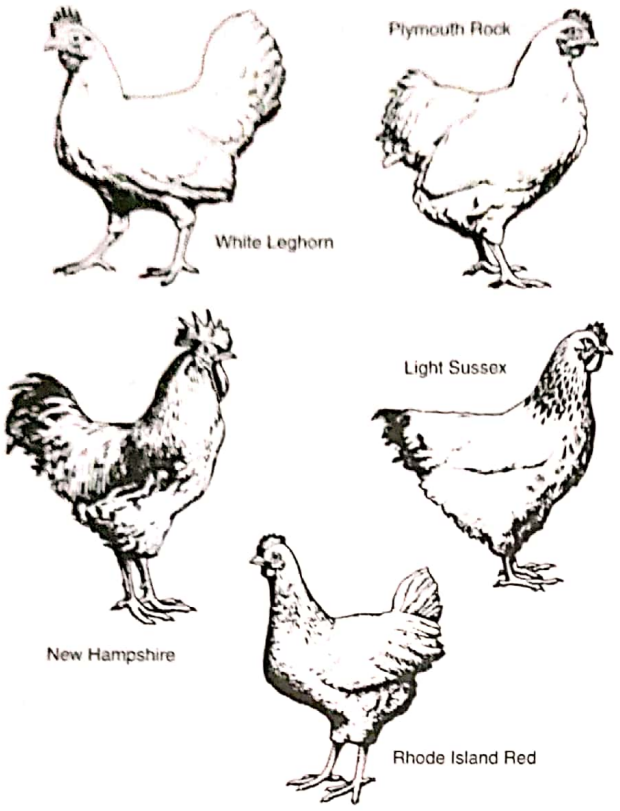


Fig 4.27 Types of fowl.

Hybrid fowl are also available. These are fowl of proven qualities produced as a result of cross-breeding between local and exotic breeds. Most hybrids are dual-purpose (see below).

Types of fowl

Fowl are classified into types, namely broilers, layers, dual-purpose and breeders, on the basis of the primary purpose of keeping them.

Broilers

A broiler is a young chicken of either sex kept mainly for meat production. Broilers are usually matured at eight to ten weeks and weigh 1.8–2.0 kg at the time of marketing. They have tender meat and have a flexible breast-bone cartilage. Rhode Island Red, Plymouth Rock, New Hampshire and Dark Cornish are suitable breeds for broilers. Broilers that are allowed to grow to 12 to 16 weeks, weighing 2.8 to 3.6 kg are described as **roasters** as they are suitable for roasting.

Layers

Layers are raised mainly for egg production. They are usually smaller in size and consume less feed. They are generally nervous and difficult to confine. They do not often go broody. Suitable breeds are Brown and White Leghorns, which lay brown and white eggs respectively. A good layer should lay 16 or more eggs a month. Characteristics of good layers include large, glossy, bright and warm combs, bright eyes, and an enlarged, oval and moist vent.

Dual-purpose types

These are good layers and also produce meat of high quality. They include Light Sussex, Black Austrolop and Rhode Island Red.

Breeders

These are fowls (cocks and hens) of proven qualities, normally kept in a deep litter pen to cross and produce fertile and hatchable eggs. Eggs produced by breeders are often hatched into day-old chicks through artificial incubation.

ACTIVITY 2 Identifying breeds and types of fowl

1. Visit the school poultry farm and/or other poultry farms in the neighbourhood.
2. Carefully observe the fowl in terms of body size and shape, plumage colour, combs and wattles, eye colour and brightness.
3. Record your observations. Use Figure 4.28 as a guide.
4. Identify the breeds and types of fowl in the poultry house.
5. State whether any layers observed are good layers or not.

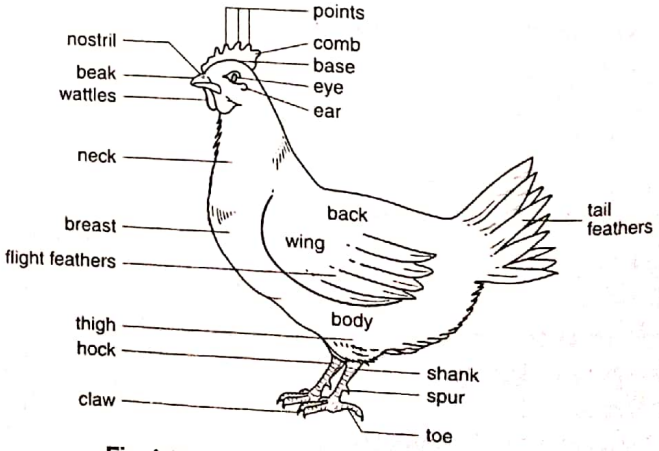


Fig 4.28 External features of a chicken.

Management of chicks

Day-old chicks can be obtained from reputable sources such as Darko Farms and Akate Farms in Kumasi, and Afariwaa Farms in Tema and Reiss and Co. in Accra. These companies use artificial incubation to produce day-old chicks on a large scale.

Incubation

Incubation is the process of keeping fertile eggs under conditions favourable for the development of the embryo into chicks within a period (**incubation period**) that depends on the kind of poultry. For fowl, the incubation period is 21 days; for ducks and turkeys it is 28 days.

Incubation may be natural or artificial. In natural incubation the hen sits on her eggs to provide the necessary conditions for hatching them. In artificial incubation, incubators are used to hatch relatively large numbers of eggs; the number depends on the size of the incubator used.

A temperature of about 38°C is required to provide the warmth necessary to ensure successful incubation. A humidity (moisture content of the air) of about 60 per cent for the first 15 days and 90 per cent for the last week of incubation are ideal for successful incubation. Other necessary conditions include turning of eggs, adequate ventilation and control of diseases.

Brooding

Day-old chicks are managed in a **brooder house** – a house designed and equipped to provide the rearing requirements of chicks on a large scale. A brooder house is normally located at least 90 m away from other/older birds to prevent or minimise the transmission of diseases to the chicks. Together, the routine practices carried out to ensure the health, comfort and growth of the chick is known as **brooder house management**.

The most crucial factor during brooding is temperature. This is because chicks have no feathers to help them in the regulation of their body temperatures. Favourable temperatures are particularly important during the first three weeks of life. Recommended temperatures for this period are, week one: 32–35°C; week two: 29–32°C; week three: 27–29°C. The relative humidity of the brooder house should be between 55 and 70 per cent.

The floor of the brooder house should be covered with a suitable litter material to a thickness of about 5 cm. Wood shavings or straw are often used for this. Small-grained sawdust is not suitable as this can block

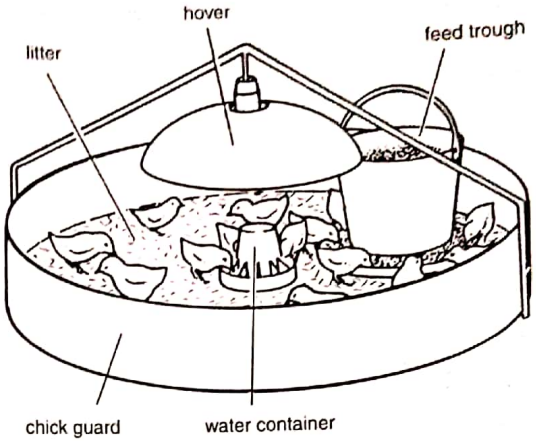


Fig 4.29 Day-old chicks in a brooder.

the nostrils of the chicks and suffocate them. The feeders and waterers must also be suitable for use by chicks. The brooder house should first be swept, scrubbed, disinfected and cleaned before putting in the litter. It must have a disinfectant foot-bath at its entrance. Figure 4.29 shows day-old chicks in a brooder. The lamp has a **hover** (canopy) to concentrate the heat and the chicks are confined by a chick guard.

Before the arrival of the chicks the brooder house should be warmed to a temperature of about 35°C. Feed and glucose water should also be ready for the chicks. The glucose water gives instant energy to help them overcome the stress of transportation. On arrival the chicks must be encouraged to feed and take water by dipping their beaks several times into the feeders and waterers.

The brooder house temperature should be reduced weekly by 2–3°C until the fourth to fifth week, when an external source of heat is no longer required. By this time the chicks will have developed enough feathers to insulate themselves against cold. Poultry farmers should be able to interpret the chicks' behaviour as detailed below, and adjust the temperature accordingly:

- chicks move away from brooder and spread out with their beaks open – temperature too hot
- chicks cluster together under hover – temperature too cold.

It is also important to allow enough space for chicks in the brooder house to enable them to feed, drink and move about freely. Crowded chicks do not grow well. The recommended spacing is 0.05 m^2 per chick in the first week, increasing to 0.1 m^2 per chick by the fourth

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week. Thus 100 day-old chicks would require a total floor space of 5.0 m^2 in the first week and 10.0 m^2 by the fourth week. At six weeks, the chicks are mature enough to go into a pen.

Other important brooder house management practices aimed at raising healthy chicks include:

- good ventilation in the brooder house
- control of human traffic to the brooder house
- visiting brooding chicks first before older birds
- debeaking chicks at two to three weeks old
- strictly following the recommended medication and vaccination schedules.

Equally important is record keeping on source and number of chicks, medication and vaccination, weekly feed consumption and daily mortality.

ACTIVITY 3 Visiting a brooder house

1 Visit the school brooder house or a local poultry farm.
2 Estimate the distance between the brooder house and the nearest poultry pen.
3 Observe and describe the source of heat, hovers, chick guards, waterers and feeders, and foot-bath.
4 Find out what the thermometer and hygrometer are used for.
5 Ask the farmer about the following:
   a) his/her source of day-old chicks
   b) preparations made to receive the chicks
   c) management practices being carried out
   d) medication and vaccination schedules
   e) records kept.
6 Write a report on your visit.

Poultry-keeping systems

Poultry keeping is classified as extensive, semi-intensive and intensive (Figure 4.30). Generally, the type of fowl kept (broilers or layers), the location of the farm, the farmer's economic status and his/her level of poultry-keeping skills determine the choice of poultry-keeping system used.

Extensive system

This is the oldest form of poultry keeping in West Africa and is mainly practised by peasant farmers using local breeds. It is characterised by a low stocking rate (750 to 1000 birds per acre), little or no housing facilities and birds being largely left to fend for themselves.

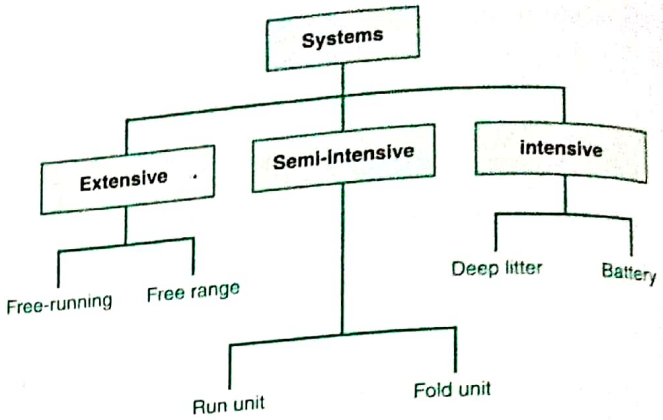


Fig 4.30 Poultry-keeping systems and examples.

Where the birds are allowed an unlimited scavenging area such as a whole village and its surrounding bushes, the system is referred to as **free running**. Where they are allowed to run freely over an area of fenced grassland it is known as **free range** (Figure 4.31).

In the free running system, the birds are often found roosting at night on walls in the home or on tree branches near the house. At best, they are provided with chicken coops and occasionally given some supplementary food by their owners. The chicken coop is often constructed from cheap, local materials, such as wood or pieces of bamboo. It is raised above ground level and has a backward slanting roof and open-front compartments in tiers. These are used by the birds for night shelter and sometimes as nests for natural incubation.

The extensive system has the advantage of low capital outlay for housing, equipment and feeding. Disadvantages are the risks of exposure to adverse weather conditions, predators and theft, as well as disease and parasite infestation.

Semi-intensive system

This system provides the fowl with some form of housing facilities, as well as freedom to roam in a

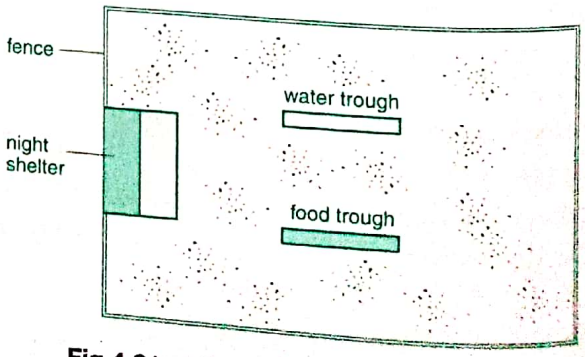


Fig 4.31 Plan of free range system.

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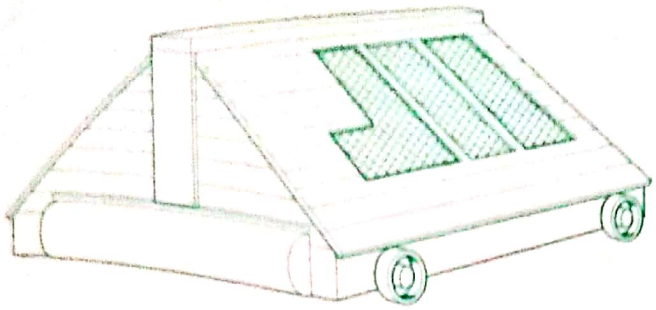


Fig 4.32 Fold unit system.

limited area in the day time. Stocking rate is about 4000 birds per acre.

The **run unit system** has fixed housing surrounded on two sides by fenced grasslands called runs. During the day, the fowl help themselves to grasses, worms and grit. The fixed house is used for shelter at night and during adverse weather conditions in the day time. The two runs are used alternately in six to 12 month cycles.

The **fold unit system** uses a movable house with an enclosed run (Figure 4.32). The chickens roost in the house at night and use the run during the day. The run is covered from below by wire netting to prevent snakes and other predators from entering the unit. The whole unit is moved daily to new and cleaner areas of grassland.

The advantages of the semi-intensive system are:

- birds are protected from predators and adverse weather
- it is suitable for all ages of birds
- low capital investment is required in terms of housing
- it is good for commercial egg production
- it is ideal for backyard poultry keeping
- birds have access to natural vegetation and sunshine.

The disadvantages are:

- problems such as feather picking, egg eating and cannibalism may occur
- the system is only suitable for relatively flat land
- labour is required for the daily moving of the fold units.

Intensive system

In this system birds are totally confined in well-ventilated poultry houses. The stocking rate is high (12 000 birds per acre). There are two types of intensive system – deep litter and battery.

The following factors are necessary for the selection of a good site for a poultry house:

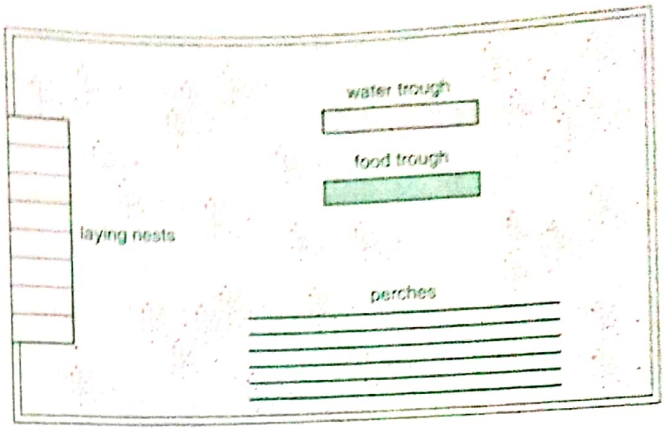


Fig 4.33 Plan of deep litter pen for layers.

- well-drained, flat land
- close proximity to sources of water and electricity
- enough land for future expansion
- area not too shady
- accessible from good roads.

Deep litter system

Birds are housed in well-ventilated pens with a litter of wood shavings, sawdust or cut straw. This system is used for broilers, layers and breeding stock. Ordinary or automated feeders and waterers are used. Egg-laying nests are provided in pens in which layers are kept (Figure 4.33).

The advantages of a deep litter system are:

- increased production as a result of more efficient management
- no loss of birds or eggs
- birds feed and drink in relative comfort
- birds are protected from predators and adverse weather
- the small amount of ammonia gas produced during the decomposition of the litter disinfects the pen against coccidiosis (see 'Diseases and parasites of poultry').

The disadvantages are:

- birds have no access to natural vegetation, insects, worms or natural light
- cannibalism may result from overstocking (overcrowding)
- high initial capital is required for housing and poultry equipment
- diseases and parasites spread more quickly
- dirty litter may soil eggs or cause their breakage
- record keeping on individual birds is not easy.

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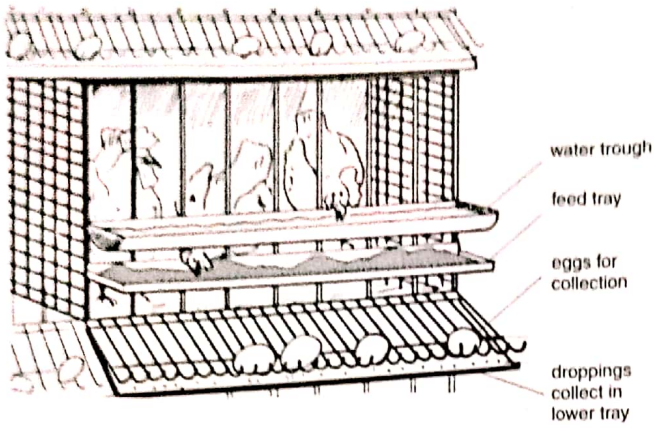


Fig 4.34 Battery cages.

Battery cage system

This is the most popular system for the production of broilers and eggs on a commercial scale. The birds are kept for the whole of their productive life in wire-mesh, galvanised or wooden cages large enough to allow them room for sitting, standing and limited movement. Depending on the design, each cage houses one or two birds. Each cage has water and feeding troughs attached. Eggs are collected from a rack at the front. The wire-mesh floor is forward slanting and has a tray under it for the collection and disposal of droppings. The cages are arranged on top of one another in tiers (Figure 4.34).

The advantages of the battery system are:

- it is labour saving
- low incidence of diseases and parasites
- better record keeping on individual birds
- eggs are clean and free from breakages
- birds are easily viewed and reached for the purpose of culling
- needs little housing space
- less noisy because of the limited interaction of birds
- better feed and water utilisation
- low incidence of disease
- cannibalism is virtually absent.

The disadvantages are:

- battery cages are expensive to buy and maintain
- cages are prone to technical faults because of automation of equipment
- cannot be used for brooding chicks or breeding purposes
- birds suffer from cage fatigue due to inadequate exercise
- cage confinement results in leg weakness, wounds resulting in lameness and breast blisters
- birds have no access to natural food.

ACTIVITY 4 Visiting deep litter and battery cage poultry systems

1 Visit poultry farmers practising the deep litter system and battery cage systems, or visit the school poultry farm if these systems are used.

2 *Work in groups*. At the deep litter pen carry out the following:
   a) Determine and record the area of the pen(s).
   b) Count the number of birds in the pen(s) or obtain this information from the farmer.
   c) Calculate and comment on the stocking rate of the birds.
   d) Observe and comment on the cleanliness of feeders and waterers, the interior and surroundings of the pen.
   e) Ask the farmer about problems often encountered.

3 At the battery cage pen carry out the following:
   a) Count and record the number of birds in each cage.
   b) Count and record the number of cages per tier, and the number of tiers.
   c) Observe and comment on the cleanliness of the feed and water troughs, the tray for collection of droppings and the egg rack.
   d) Listen to and compare the noise level of birds to that in the deep litter pen.
   e) Ask the farmer about problems often encountered.

Feeding poultry

Feeding chickens

Birds grow well when fed on adequate quantities of a balanced diet, that is feed containing all the necessary nutrients in the right proportions. Balanced diets vary depending on the age and type of birds. Some essential nutrients and their sources are given in Table 4.10. At all stages of growth chickens should be provided with adequate amounts of clean, fresh water.

Table 4.10 Feed nutrients and their sources

Nutrient	Source
protein	fishmeal, bloodmeal, groundnut cake meal, soyabean meal, cotton seed cake
carbohydrate	maize, sorghum, wheat bran, rice bran
minerals	bone meal, oyster shell meal, common salt
vitamins	green forage, yeast, vitamin premix
fats and oil	groundnut cake meal, soyabean meal, cotton seed meal

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Table 4.11 shows the compositions of growers mash, layer finisher and broiler finisher. The feed ingredients in these mashes have been carefully formulated to provide the nutrient requirements of the different types and classes of bird. When the feed ingredients are added together (compounded) according to their respective percentages they give balanced rations for the birds.

Table 4.11 Feed nutrients and their sources

Ingredient	Amount (%)		
	Growers mash for layers	Layers mash	Broiler finisher
maize	53.50	52.00	61.50
wheat bran	35.00	25.00	5.00
groundnut cake	6.00	7.50	20.50
fishmeal	2.50	7.50	7.00
oyster shell	2.00	7.50	1.50
copra cake	–	–	4.00
dicalcium phosphate	0.50	–	–
salt	0.30	0.25	0.25
vitamin premix	0.20	0.25	0.25
Total	100	100	100

Feeding broilers

Broiler day-old chicks are fed on broiler starter mash until they are four to five weeks old. From then onwards, they are fed on broiler finisher mash until they are sold or slaughtered at eight to ten weeks of age. Broilers should be given adequate feed and enough feeding and drinking space to maximise growth. A well-fed and well-managed broiler should reach an average live weight of 1.5 kg at eight weeks and 1.8–2.5 kg at ten to 12 weeks.

Feeding layers

Layer chicks are fed on chick starter until they are six weeks old. Chick starter contains 22 per cent protein, 1.1 per cent calcium and 0.5 per cent phosphorus. Between eight to 20 weeks, layers are referred to as 'growers', and are therefore fed on growers mash. This feed contains 16 per cent protein, 0.95 per cent calcium and 0.4 per cent phosphorus. From 22 weeks onwards the birds start laying eggs and are now known as layers. Logically, therefore, they are fed on layers mash, composed of 17 per cent protein, 3.4 per cent calcium and 0.53 per cent phosphorus. An adequate supply of clean water is particularly important for layers at all stages.

The minerals, calcium and phosphorus in the layer ration contribute to the formation of the egg shell. The protein in the diet provides essential components of the egg yolk and albumen (egg white). An average size egg consists of 11 per cent shell, 58 per cent albumen and 31 per cent yolk.

Management practices

Poultry management practices are collectively aimed at enhancing the performance of the birds. Some involve the maintenance of general sanitation and as a result prevent diseases and parasites, while others prevent cannibalism and other vices.

Poultry management practices are routine or periodic. The routine ones, often performed on a daily basis, include cleaning the poultry pen, equipment and surroundings. Periodic management practices are carried out once, twice or three times in the life of the birds. Some of these involve medication including deworming and vaccination. Others are culling and debeaking.

Vaccination

Poultry birds are to be vaccinated according to a vaccination schedule to protect them against such diseases as Newcastle disease, Gumboro disease and fowlpox (see 'Diseases and parasites of poultry'). Vaccines may be administered orally through the water or through injection.

Culling

Culling is simply the removal of unproductive, poorly performing or sick birds from the flock. For this purpose poor productivity or performance is measured by poor growth rates in the case of broilers and low egg-laying capacity in the case of layers.

The advantages of culling are:

- more space created for the rest of the flock
- a reduction in the spread of diseases and parasites
- a cost saving as a result of not feeding the unproductive birds.

Unproductive birds are either sold off at give-away prices or slaughtered for food. Sick birds are isolated for treatment. Those with hopeless conditions should be disposed of by killing them and burying or burning them. Culling of birds is best done at night when the birds are quiet and less frightened.

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Debeaking

This involves cutting off about half of the upper mandible and the tip of the lower mandible of the beak of a poultry bird. It is aimed at preventing cannibalism in the form of vent pecking and egg eating within a flock.

Birds not properly debeaked, that is if their lower mandibles are severely cut, cannot eat well and may not perform well. Birds are better debeaked when young (one to two weeks old). A hot knife or a hot blade electric debeaker is used. The heat cauterises (burns) the cut beak to prevent bleeding and promote healing. Chickens should not be debeaked during the heat of the day or at a time when the birds are under any form of stress, for example soon after vaccination.

Diseases and parasites of poultry

Diseases

Many diseases affect poultry and constitute a potential source of risk to the poultry farmer. It is therefore better to prevent their outbreak than to cure affected fowl. Some common diseases of poultry are described in Table 4.12.

Other important poultry diseases include Marek's disease, chronic respiratory disease, fowlpox, fowl cholera and Aspergillosis (see Table 4.14).

Parasites

Poultry are infested by ectoparasites, including lice, ticks, mites, fleas and flies. **Lice and ticks** cause body

Table 4.12 Common diseases of poultry

Disease	Symptoms	Prevention and control
Newcastle disease – an acute poultry disease usually affecting young birds; caused by a virus.	• infected birds become paralysed and often blind • walking and falling backwards • twisting of the neck • nasal discharge and difficulty in breathing • rapid spread of disease and high mortality	Prevention: • proper sanitation • strictly following the Newcastle disease vaccination schedule. Control: No specific treatment. Immediately upon detection infected birds should be isolated and properly disposed of.
Pullorum disease – a bacterial disease mostly affecting chicks during the first two weeks of life. It is first transmitted through eggs but may also be transmitted through poultry droppings, cannibalism and egg eating.	• high mortality in newly hatched chicks • chicks often huddle together • excessive greenish-white diarrhoea • vent pasting (droppings sticking to vent area) • ruffled feathers • inflamed back joints • laboured breathing	Prevention: • strict sanitation • avoidance of stress in chicks • fumigation of incubators before use. Control: Treat infected birds with antibiotics and sulpha drugs, e.g. sulphamerazine in water for chicks.
Coccidiosis – a protozoan disease which infects both chicks and growing birds. It also occasionally affects older birds.	• high mortality in young chicks • loose and blood-stained droppings • loss of appetite • squatting at one place all day long with the head drawn back against the body or tucked under a wing • standing with eyes closed • blood-stained feathers around vent • drop in egg production	Prevention: • rigid sanitation and good litter management • burning of old litter • use of good coccidiostats in water and feed. Control: Cull infected birds.
Gumboro disease – a viral disease confined to growing birds (3 to 4 weeks old) and transmitted through unclean poultry pens and equipment.	• birds are droopy and sleepy • birds suddenly collapse and die • birds are nervous and listless • whitish diarrhoea and dehydration	Prevention: • vaccination of chicks • good sanitation • stress avoidance • use of glucose and antibiotics in water. Control: No specific treatment.

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itching, emaciation and a drop in egg production. They are generally controlled using dusting pesticides such as sodium fluoride.

Poultry are also infested by endoparasites, such as roundworms and tapeworms. **Worm infestation** is prevented by the use of dewormers as directed by the veterinary department. Deworming is particularly important for layers, in which worms cause poor growth and a reduction in egg production.

Processing, storage and marketing

Healthy fowl selected for slaughter should be starved for 24 hours beforehand, though they may be given water during that period. Starving ensures that the digestive tracts of slaughtered fowl are virtually empty of faeces that may spoil the carcasses during processing.

After slaughter, fowl should be allowed to bleed fully as this improves both the quality and the storability of the meat. The next stage is the dressing of the carcass. This involves **scalding** – dipping the carcass in water at about 65°C for around three minutes. This process soaks the bases of the feathers and makes their removal easier.

The next process, **plucking**, involves the removal of the feathers by hand or using a feather plucker. The carcass is then **singed** – exposed to a flame to burn off the hair-like filoplume feathers.

The carcass is then washed clean and **eviscerated** – cut open and internal organs removed. While the intestines, the gall-bladder and the pancreas are discarded, the heart, liver and gizzard (feed sack) are packed together as giblets and either inserted into the body cavity of the carcass or sold separately. The head is also discarded but the legs have market value. The dressed chicken is then sealed in a plastic bag for sale or for storage and preservation. The ideal storage temperature is about –18°C in a freezer.

In West Africa, dressed fowl are sold mostly to hotels and restaurants. The bulk are marketed live, especially during festive occasions such as Christmas and Easter.

Pig production

Pigs, sometimes referred to as swines, are omnivorous non-ruminant animals. They are omnivorous in the sense that they are likely to eat any plant or animal materials they come across. However, they cannot easily utilise grasses and herbage as ruminants do because of their simple stomach system. The bulk of their feeds are therefore mainly cereal grains and legumes, and roots and tubers.

Pigs are reared for meat, the fresh form of which is called **pork**. Cured products of pigs are **bacon**, **ham** and **sausages**. Other useful products of pigs are **lard** (fat), the skin and the bristles (hairs). The skin is used as leather and the bristles for making brushes.

Pig production is a very profitable venture because pigs:

- grow very fast, reaching a market liveweight of about 95 kg at age seven to eight months
- are very easy to feed because of their omnivorous feeding habits
- require small housing and growing space relative to cattle
- have a higher dressing percentage (carcase weight as a percentage of liveweight) of 75 per cent relative to that of ruminants of 50 per cent
- yield large quantities of droppings, which are useful both as organic manure and for production of biogas (gas produced by breakdown of organic material).

The major disadvantage of pig production is that pigs compete with humans for food. Their production, sale and consumption are also not allowed among people of some cultures and religions, for example, Muslim communities.

Pig breeds and their characteristics

Both local and exotic breeds of pigs are kept in West Africa.

Local breeds

Local breeds of pigs, mainly the Ashanti Dwarf pig, are normally reared under the extensive system largely in rural and semi-urban settings of West Africa. Ashanti Dwarf pigs are small and black, and are poor performers. They have low genetic potential for reproduction but have excellent resistance to pests, diseases and adverse environmental conditions.

Exotic breeds

These are breeds preferred and kept by most commercial pig farmers. This is because they are generally better performers. They include Large White, Landrace, Duroc and Tamworth (Figure 4.35). Others are Poland China, Hampshire and Berkshire.

- **Large White** (or **Yorkshire**) – muscular in body structure with a prominent stomach, wide chest and strong, solid legs. Their coat colour is white and their ears are large and erect.

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Fig 4.35 Some breeds of pigs in West Africa **(a)** Duroc boar; **(b)** Large White boar; **(c)** Landrace boar.

- **Landrace** – characterised by a white coat colour. They have a slightly concave back, long and slender body and drooping ears. In a standing position, the body is higher at the hindquarters than at the forequarters.
- **Duroc** – dark or red-brown or dark red coat colour. Their snouts are long and ears are horizontally held. They are medium-sized breeds with a nearly horizontal back, and produce a lot of lard.
- **Tamworth** – characterised by a straight head and long neck. The body, snout and the legs are also long. Their coat colour is between dark red and golden red. They have erect ears.
- **Poland China** – black coat colour, sometimes with white markings, and drooping ears. The breed is good in the production of both meat and lard.
- **Hampshire** – black coat colour with a belt of white around the legs and shoulders. They have erect ears and short legs.

Housing and management systems

Local breeds of pigs are traditionally kept under the extensive system with little or no housing, no feeding and no medication. In commercial pig production, however, the animals are reared under the intensive or the semi-intensive system. In both cases good housing is a unique feature.

Pig housing units are called **sties**. An enclosed pig farm comprising of a number of sties is known as a **piggery** (Figure 4.36).

An ideal pig sty should be designed and constructed to provide for the physiological as well as the management needs of the pig. The floor should be slanting slightly to facilitate drainage. It should also be of a rough hard concrete to avoid injuries to the pigs through slipping. The structure should be strong enough to withstand the burrowing actions of the pigs and well ventilated to prevent draughts. Additionally it should be spacious enough to avoid over-crowding and resultant cannibalism.

Separate feeding areas with water and feed troughs should be provided. **Wallows** (pools of water or mud) should also be provided. In **farrowing pens** (farrowing is the term for a pig giving birth), guard-rails (or

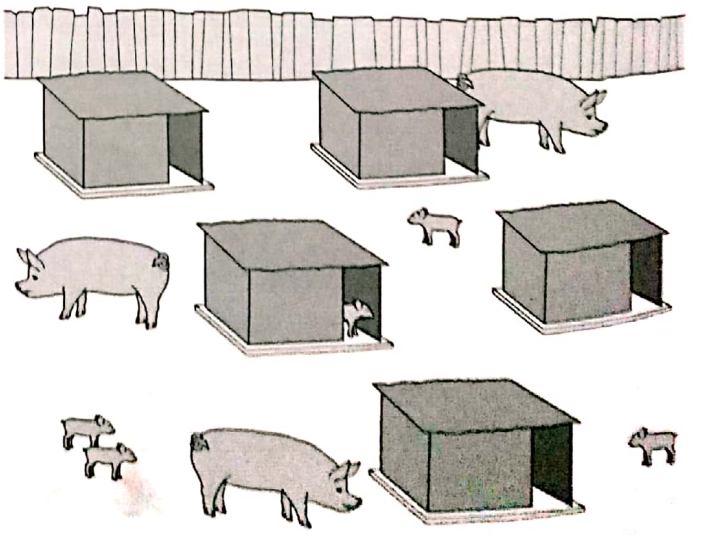


Fig 4.36 A typical piggery.

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farrowing rails) should be provided to prevent the dam from crushing her piglets.

Breeding and breeding systems

Initial selection of pigs suitable for breeding is done at weaning. The final selection is done when pigs are about six months old, an age good enough for first mating. A good breeding boar is key to successful pig production. Such a boar should be able to handle about 20 **gilts** (young females) or **sows** in one year. Hand-mating (or pen-mating) and artificial insemination are the main breeding systems used. It is always good management practice to **flush** gilts or sows a week before mating or insemination.

> **Flushing** is the practice of putting a female animal on a high plain of nutrition to stimulate ovulation and enhance conception rates and multiple births.

Pregnancy and parturition

Pregnant sows have an average gestation period of 114 days, fondly remembered as three months, three weeks and three days. A week or two before farrowing, the pregnant pig should be properly fed and dewormed. Deworming will reduce the worm burden and possible contamination of the pig's environment with worm larvae and eggs.

Signs of parturition in pigs include the following:

- udder drops and teats become pinkish-red in colour
- vulva slackens and becomes pinkish-red in colour
- milk can be squeezed out of the teats.

Preparation for farrowing during this period includes:

- washing and cleaning sows with water containing suitable chemicals that kill ectoparasites
- cleaning and disinfecting the farrowing pen of all pests, parasites and pathogens (infectious agents)
- keeping the pen dry and warm for the piglets
- moving the sows to the farrowing pens
- providing less feed but more clean fresh water to prevent constipation, which causes farrowing delay, and congestion of gut which contaminates piglets during farrowing
- ensuring that the farrowing pen is well ventilated and cool as hot weather also delays farrowing.

Caring for piglets

Without proper care and good management piglet mortality can be very high. Between farrowing and weaning piglets, the husbandry practices discussed below are recommended.

Access to colostrum

Six to 12 hours after farrowing, piglets should be encouraged to suckle the dam's teats for colostrum. This is crucial during the first three to four days after birth. Colostrum provides piglets with enough nutrients for growth and development and protects them from disease.

Cutting and disinfection of the navel

It is important that the cord of the navel is cut and disinfected with iodine soon after birth. This will prevent navel cord infection by pathogens.

Removal of canine teeth

Because of the sharp and pointed ends of the canine teeth of piglets, they should be clipped off two to three hours after birth. The objective is to prevent injuries to the teats of the dams and facial injuries to other piglets in the struggle for the dams' teats during suckling.

Iron injection

Piglets do not get enough iron from the milk of the dam to supplement their blood iron content for haemoglobin formation. Under the extensive system, where piglets have access to soil and vegetation, they take in considerable amounts of iron. Under the intensive system, however, piglets should be given iron injections, for example, iron-dextrin, within the first week of life. A second injection of a suitable iron compound is recommended at two to three weeks of age. Enough iron in the blood of piglets will not only enhance their growth, but will also help prevent **piglet anaemia**, one of the leading causes of piglet mortality.

Creep feeding

Piglets have immature and weak digestive systems making it difficult for them to efficiently utilise normal feeding stuffs given to growing and adult pigs. As a result, they are to be given very nutritious, balanced and easily digestible feed away from the dams – a process known as creep feeding. This husbandry practice facilitates the growth of piglets and speeds up the weaning process. It also compensates for the declining milk yields of the dams as the piglets advance in age.

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Castration

Male piglets not being reared for breeding purposes can be castrated when they are three to four weeks old. It is easier to handle the piglets for castration at this early age. Castration stress is minimal and wounds of castration (if any) heal faster. Regardless of the method used, castration instruments should always be clean, and the practice should be carried out under good sanitary conditions. This will prevent post-castration losses caused by tetanus infection. Castrated piglets are called **barrows** as opposed to **hogs** or **stags**, which are adult pig castrates.

Provision of warmth

Piglets do not have a physiological mechanism for regulating their body temperatures appropriately. This can result in their death through chilling. Piglets should therefore be provided with sufficient warmth. The floors of farrowing pens should be well drained, dry and covered with warm straw.

It is also important to provide overhead heat in the form of electric bulbs or infra-red lamps. This will attract the piglets away from the dam where they seek warmth, and drastically reduce the possibility of being crushed by the dam when she lies down.

Table 4.13 gives information about the critical environmental temperature requirements of pigs from birth to adult age.

Weaning

At about six weeks of age, piglets should be weaned (separated) from the dam. Weaning frees the dam for re-breeding and gives weaners the opportunity to benefit from appropriate husbandry practices. Weaners should be sexed and grouped into young boars and gilts. This will prevent in-breeding among litter mates when they attain sexual maturity. They should also be given identification for better record keeping and management practices.

Table 4.13 *Critical environmental temperatures for pigs*

Age of pig/piglet	Approximate critical environmental temperature
Newly born piglets	35°C
One week old piglets	30–35°C
Two to three weeks old piglets	30°C
Weaners (6 to 8 weeks)	25–29°C
Growers (2 to 6 months)	20–25°C
Adult pigs (over 6 months)	10–12°C

Management of growing pigs

The management of growing pigs until slaughter is relatively less demanding. Good feeding, housing and the prevention and control of pests, parasites and diseases are, however, key to rapid economic gains from a piggery business.

Feeding

Feed at this stage should be adequate and balanced to provide the nutrient requirements of the pigs for rapid growth and development. The diet should include cereal grains, roots and tubers for energy; fish meal, soyabean meal, groundnut cake and blood meal for proteins and minerals; and discarded fruits and herbage for vitamins. Adequate supply of fresh clean water in the sty at all times is highly recommended.

Housing

Pigs have no sweat glands and as they grow they also accumulate a lot of subcutaneous fat, making it difficult for them to lose body heat through perspiration. This stressful physiological problem, which can cause heat burns, can be solved by avoiding over-crowding and through the provision of wallows and good ventilation in the sty.

Parasites and disease control

- **Ectoparasites** – major parasites living on pigs are ticks, lice, mites, fleas and flies. All of these can be controlled through dipping, spraying and washing with water containing recommended chemicals.
- **Endoparasites** – the main parasites living inside pigs are tapeworms and roundworms. When they infest pigs, they enter the intestines of the host and cause diarrhoea, coughing and unthriftiness (failure to grow or gain weight at a normal rate in spite of an adequate diet). Infested pigs have pot bellies and are stunted in growth. Periodic deworming of pigs is the surest way of preventing and controlling worm infestation.
- **Diseases** – African swine fever, trypanosomiasis and brucellosis are some of the major diseases of pigs in West Africa. Others are mastitis, mange and scours. Details of most of these diseases are given in Tables 4.9 and 4.14.

Finishing, processing and marketing

Pigs are matured for slaughter when they are six months old and above. Pigs selected for slaughter should be healthy and should be given sufficient pre-slaughter care to ensure good meat quality.

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Table 4.14 Details of some animal diseases

Disease	Pathogen	Animals affected	Transmission	Symptoms	Prevention and control
African swine fever	virus	pigs (swine)	direct contact with contaminated food, water and equipment; wild pigs are carriers	high fever, anorexia; coughing and vomiting; diarrhoea; foul-smelling discharges from the nose and eyes; paralysis of the hindquarters	good hygiene; quarantine; breeding for resistance; isolation and destruction of affected pigs
rabies	virus	cattle, dogs, cats, humans	through the saliva of the infected animal	profuse salivation; paralysis and dumbness; voice changes; refuses water and is sometimes frightened by the sight of water; hiding in dark corners; furious without provocation	quarantine; vaccination; destruction of animal in acute cases
blue tongue	virus	sheep	by midges	intensive fever, loss of appetite; nasal discharge; mouth ulcers; lameness; coughing	seek veterinary assistance; slaughter infected animals
tuberculosis	bacterium: *Myo-bacterium tuberculosis*	all livestock and humans	inhalations of bacteria, contact and food	coughing; laboured breathing; chronic illness; loss of coat colour, diarrhoea; discharges from mouth and nose; death	seek veterinary assistance; slaughter infected animals
heartwater	rickettsia: *Cowdria ruminantium*	cattle, sheep and goats	ticks (*Amblyommo* spp.)	intense fever, walking in circles; paralysis; pericarditis; protruding tongue; galloping movement; collapse and death	action against ticks; anti-heartwater serum vaccination; use of antibiotics
Redwater (babersiosis)	protozoon *Babersia* spp.	cattle, sheep, pigs, dogs	ticks	loss of appetite; red urine due to breakdown of red blood cells; stiff walking; pale and yellowish mucus membrane; abortion in pregnant animals; salivation; anorexia; death	use antibiotics and sulpha drugs; action against ticks; vaccination; strict sanitation
foot rot	bacterium: *Fusiformis nodosus*	sheep, goats, cattle, pigs, donkeys	open wound; contaminated water, contact	swollen foot; acute lameness; sore hooves; anorexia; sudden high body temperature; cracked and ulcerated interdigital spaces; inability to rise	use of dry bedding in pens; use of antibiotics on sores; good sanitation; provision of copper sulphate formalin footbath; intravenous injections of recommended sulpha drugs; isolation
Aspergillosis: (brooder pneumonia)	fungus: *Aspergillus fumigatus*	poultry, especially fowl chicks during brooding	contaminated wet litter; mouldy feeds, especially groundnut cake	difficulty in breathing; dull comb and skin; high chick mortality rate	use clean feed, water and equipment; culling of sick birds; use of antibiotics in feed and water; spray litter with phenyl-mercuric chloride solution
tetanus (lockjaw)	bacterium: *Clostridium tetani*	most livestock and humans	wounds; contaminated deep cut	muscle spasm; limb stiffening; jaws cannot move; profuse sweating; increased insensitivity of skin; careful chewing and swallowing; death	prevent wound infections through anti-tetanus serum immunisation; give glucose saline; give tranquillisers to relax muscles

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Pigs should first be stunned before slaughter and then well bled to improve meat quality and storage. The whole carcass is then **scalded**, that is drowned in hot water at a temperature of about 64°C for three to four minutes. This loosens the bases of the hairs which are then scraped off the body. The next process is **singeing**, involving the exposure of the carcass to a flame to burn off the smaller hairs. The carcass is then washed with cold water and cleaned ready for **evisceration**. Evisceration involves cutting off the head and opening up the carcass to remove all internal organs.

The carcass is again washed with cold water and split into half. Wholesale cuts of pork are then made. The cuts include the head, shoulder, ham, loin and bacon. These cuts may be sold fresh or frozen. They may also be treated or cured and preserved by salting, drying or grinding and canning for future sales.

ACTIVITY 5 Visiting a piggery

1 Visit the school piggery or a nearby piggery to undertake the following activities.
2 Identify available breeds of pigs.
3 Observe the design of the pig sties.
4 Discuss with the farmer(s):
   a) how breeding stocks are selected
   b) how piglets are cared for and weaned
   c) the causes of piglet mortality
   d) some common pests, parasites and diseases of pigs.
5 Observe some management practices carried out on the farm.
6 Observe operations involved in the slaughter of pigs and processing of the carcass.
7 Observe how wholesale cuts are made.
8 Find out how pork is treated and preserved.

Rabbit production

Rabbits are small herbivorous non-ruminants. They are raised mainly for their meat, but their wool, fur and pelt (skin) are other useful products for the clothing and handcraft industries. It is also not uncommon to find some people keeping rabbits for recreation and pleasure.

Rabbit keeping has the following advantages:

- the initial investment capital for keeping rabbits is small
- rabbits are very prolific animals as each **doe** (adult female rabbit) can produce up to 30 or 40 **bunnies** (young rabbits) in a year
- they require little housing space
- they are easy and cheap to feed as they do not compete with humans for food
- handling rabbits is less risky making it possible for the aged, the physically-challenged and even children to rear them
- rabbits do not have as many deadly diseases as some other farm animals
- they are ideal for teaching and laboratory experiments
- rabbit droppings are valuable as organic manure.

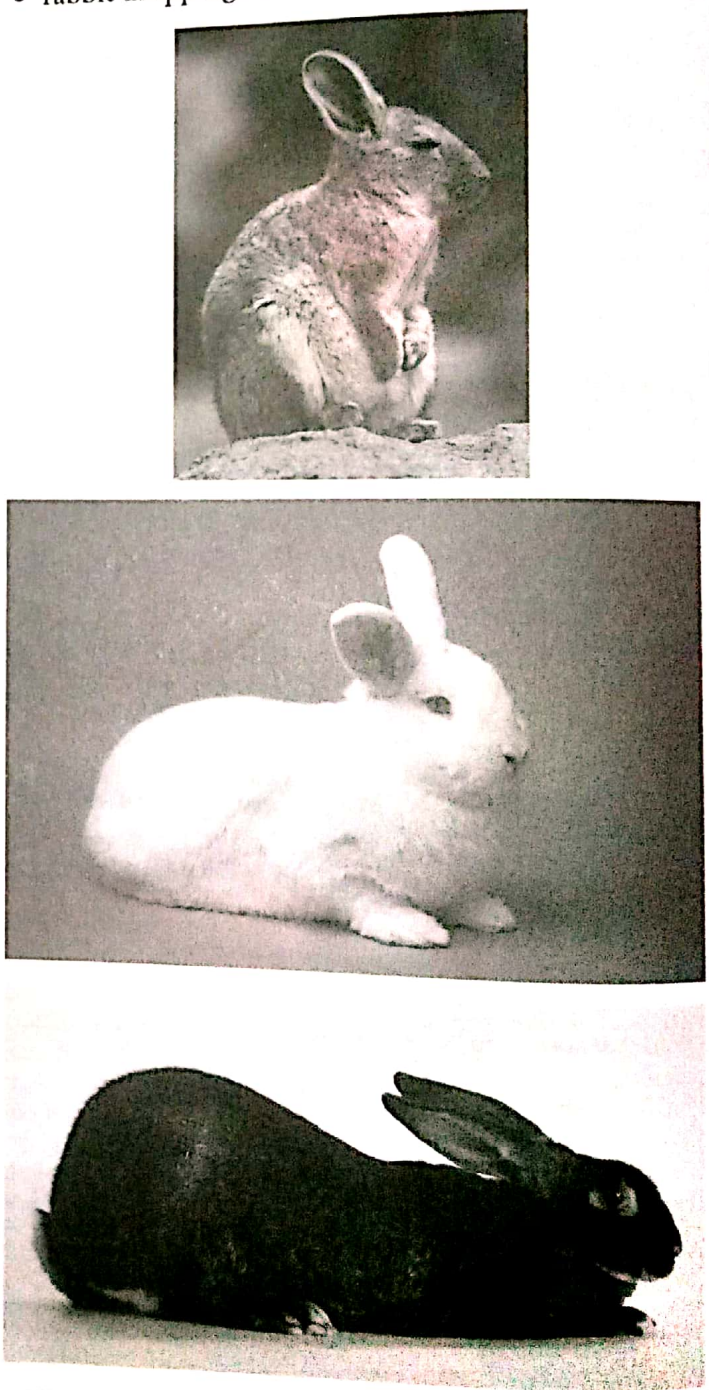


Fig 4.37 Common exotic breeds of rabbits in West Africa **(a)** Chinchilla; **(b)** New Zealand White; **(c)** Flemish Giant.

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Breeds and their characteristics

Breeds of rabbits kept in West Africa are mainly exotic breeds. Ghana, however, has a local breed which has a small and thin body conformation and black, white, or a mixture of black and white colouring.

Commonly reared exotic breeds of rabbits in West Africa include the **Chinchilla**, **California White**, **New Zealand White** and the **Flemish Giant** (Figure 4.37). Important features of these breeds are outlined in Table 4.15.

Breed selection and breeding

Rabbits are selected for rearing using the following criteria:

- prolificacy (abundance of offspring)
- mothering ability
- resistance to pests and diseases
- adaptation to local conditions
- matured weight
- longevity (ability to live long)
- carcass quality.

On average, the **buck** (male rabbit) and the doe are sexually matured for mating when they are at ages seven months and six months old respectively. Normally a doe that shows signs of heat is taken to a buck in its hutch (rabbit house) for mating. The reverse process of taking a buck to a number of does in their hutch is not advisable, as this often triggers jealous fighting among the does. Leaving a doe with a buck overnight is long enough to ensure successful mating. The recommended sex ratio for rabbits is one buck to ten does. In order to conserve its vitality a buck should not be allowed to mate more than four times a week.

Table 4.15 Features of some exotic breeds of rabbits

Breed name	Colour	Body conformation	Purpose
Chinchilla	Grey, greyish-blue or deep grey	Long body, erect and backward slanting ears	Meat and fur
California White	White body with black ears, nose and tail	Medium body length, straight back, erect and backward slanting ears	Meat, very prolific
New Zealand White	White	Broad shoulders and back, large backward slanting ears, pinkish eyes	Meat and fur
Flemish Giant	Grey or greyish-brown	Large body and raised back; a heavy breed	Meat mainly

Pregnancy in does is detected by observing the following signs:

- increased body weight
- refusal to be mated
- decrease in feeding and drinking
- frequent sleeping.

Kindling and care of bunnies

Parturition in rabbits is called **kindling** or **littering**. Pregnant does kindle or litter after an average gestation period of 30 days. The number of bunnies per kindling, referred to as **litter size**, can be as high as 15, but eight to 12 bunnies is more common.

Bunnies are born with their eyes closed and without fur to keep them warm. They are kindled into nest boxes often at night. The **dam** (mother rabbit) pulls fur from her belly and uses it to cover the bunnies to provide warmth. Ten days after kindling bunnies open their eyes. In another ten days, when their fur has developed, they venture out of the nest boxes. Their major source of food up to this time is milk from suckling at the dam's breast.

At about four weeks bunnies begin to feed on green feed stuffs. By the time they are eight to ten weeks old their desire for milk declines, making it convenient to wean them. After weaning, bunnies (now called **weaners**) should be sexed into males and females. This is to prevent premature mating among litter mates.

Housing

A rabbit house is called a **hutch**, and a rabbit farm comprising of a number of hutches and other essential farm structures is a **rabbitry** (Figure 4.38).

A hutch is constructed with wood and metal gauze or wire-netting. The roof, which is backward slanting, is preferably made out of thatch to keep the house cool. The floor is made of wire mesh to facilitate the fall of rabbit droppings through the holes. The floor is, however, covered with straw to provide warmth and comfort for the rabbits. The straw together with some droppings makes a useful manure. Equipment such as

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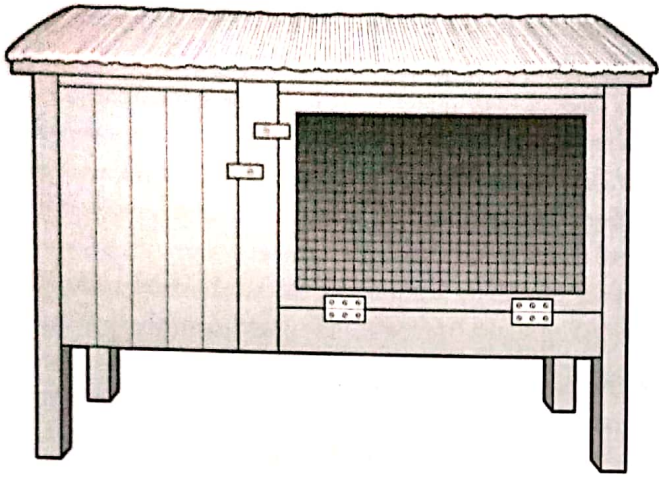


Fig 4.38 A typical rabbit hutch.

water and feed troughs as well as nest boxes are provided in most hutches. The whole structure is normally raised above the ground on four legs to protect rabbits from predators and to ensure good sanitation.

It is recommended that a rabbitry housing a **colony** (group) of rabbits should be sited in a quiet, safe and comfortable place. It should be fenced to keep away dogs and other predators, as well as thieves and intruders.

Feeding

Rabbit feed consists of a wide range of both fresh and dried forage and concentrate pellets or mashes formulated and compounded from cereal grains and legumes. The fresh forage includes rabbit weed, waterleaf, guinea grass, Centrosema and discarded lettuce and cabbage leaves.

Proper feeding of rabbits requires that they are fed *ad libitum*, that is given free access to food, allowing them to self-regulate intake according to their needs. Feeding should occur early in the morning and in the evening on a regular basis. As nocturnal animals, rabbits tend to feed more at night, suggesting that the evening feeds should be heavier than the morning ones. Adequate fresh and clean water should always be available in the hutches for the rabbits.

Handling

Proper handling of a young rabbit involves taking of a gentle grasp of the loose skin over the neck and shoulders and lifting it up gently, as shown in Figure 4.39(a). In the case of adult rabbits, which logically are heavier, the lifting is done as in the case of the young rabbit but the free hand should be used to support it from below, as shown in Figure 4.39(b).

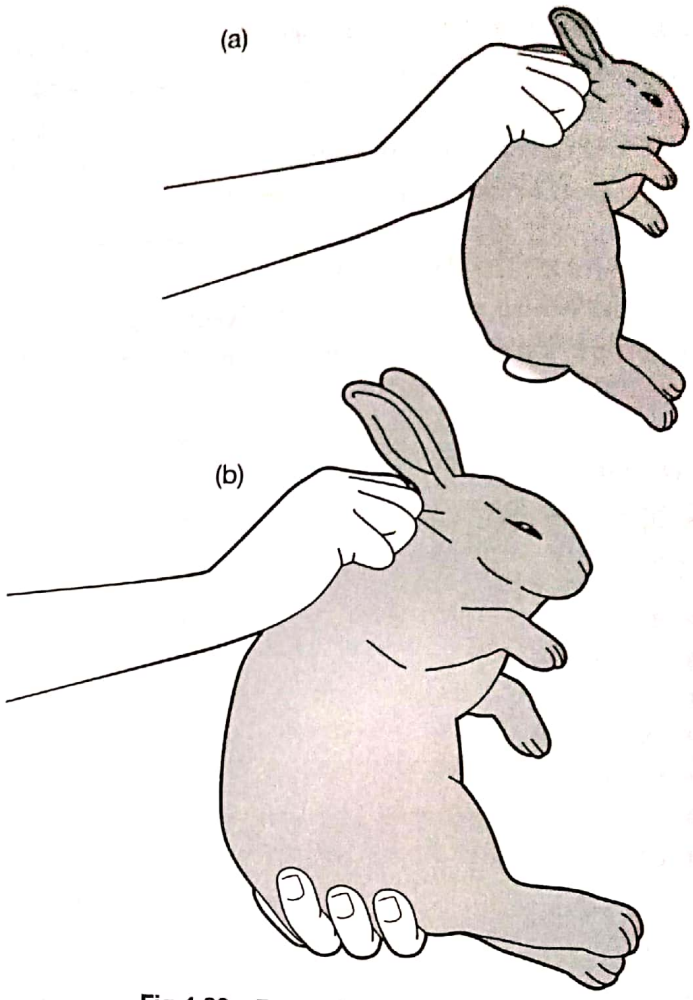


Fig 4.39 Proper handling of rabbits **(a)** young rabbit; **(b)** adult rabbit.

Pests, parasites and diseases

Pests and parasites

The major parasites of rabbits are mites, ticks and lice (ectoparasites), and tapeworms and roundworms (endoparasites). The ectoparasites are controlled through good sanitation and spraying or dusting with appropriate chemicals. The endoparasites are controlled through hygienic feeding, good sanitation and keeping away carriers of the worms such as snails, cats, etc.

Diseases

Some important rabbit diseases are coccidiosis, ear mange/canker and myxomatosis.

Coccidiosis is a protozoan (single-cell organism) disease which affects the liver and intestines of rabbits. Its symptoms include diarrhoea, the development of a pot belly and emaciation. The disease may take a complicated turn due to secondary bacterial infection. Its full control is therefore not limited to the administration of sulphur drugs but it also includes the use of antibiotics.

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Ear mange/canker is caused by mites introduced through contaminated feeds and other unsanitary conditions. It is seen as brown or yellow scaly crusts in the ears of the infected rabbits. Such rabbits scratch their ears and shake their heads frequently. Careful scratching and removal of the scales and crusts from the ears and soaking their sites with a mixture of iodine and palm oil for about a week provides an effective cure for the disease.

Myxomatosis is a very contagious viral disease. The virus is transmitted by carriers such as fleas and mosquitoes through biting and stinging. Inflammation and swelling of the eyes, nose, ears and genital organs of the infected rabbits, accompanied by high fever and loss of appetite, are its main symptoms. The disease is not curable and where the rabbit has no immunity may lead to death. Good hygiene and sanitation may help to prevent outbreaks.

Skin mange, pneumonia, conjunctivitis and **enteritis** are other diseases of rabbits.

Finishing, processing and marketing

Finishing rabbits involves putting them on diets good enough to fatten them for sale or for slaughter. This is done two to three weeks before their average maturity age of five to six months. A week before slaughter rabbits fed on grass should be fed on concentrate to improve their meat quality by reducing grass flavour.

To further improve meat quality rabbits should not be fed a day before slaughter. Slaughtered rabbits should also be well bled before skinning them. The carcass should be washed clean and hung for an hour or two for it to drain before storage, curing or packaging for sale.

The fresh pelt (skin) should be washed and cleaned of blood and dirt before being sun-dried for sale.

ACTIVITY 6 Visiting a rabbitry

1 Visit the school or nearly rabbitry to undertake the following activities.
2 Observe and identify breeds of rabbits kept in the rabbitry.
3 Observe hutches and their structural features.
4 Discuss with farmers husbandry practices such as breeding, feeding, sexing, handling and the control of pests, parasites and diseases.
5 Observe or take part in the slaughter and processing of rabbits and their by-products.
6 Find out from farmers how rabbits and their products are marketed.

Self check

For questions 1 to 20, choose the letter that refers to the correct option.

1 Which one of the following livestock breeds is exotic?
A Muturu B Aberdeen Angus
C N'dama D Zebu

2 The loose fold of skin which hangs from the throat of Zebu cattle is called:
A dewlap B hump
C udder D withers

3 The oestrus period of a cow is:
A 17 days B 19 days
C 21 days D 23 days

4 Both ewes and nanny goats have the same gestation period of:
A 120 days B 150 days
C 200 days D 280 days

5 Which chamber of the digestive system of ruminants regurgitates cud for chewing?
A rumen B reticulum
C omasum D abomasum

6 Which livestock identification method sometimes uses liquid nitrogen at –70°C?
A branding B tattooing
C ear tagging D ear notching

7 Which of the following is a bacterial disease of farm animals?
A foot and mouth B heartwater
C anthrax D Redwater

8 Which livestock condition is controlled using the trochar and cannula?
A bloat B brucellosis
C mastitis D tetanus

9 All of the following are symptoms of bloat, except:
A profuse salvation B reproductive failure
C laboured breathing D staggering

10 Which of the following breeds of fowl is a dual-purpose type?
A Brown Leghorn B White Leghorn
C Rhode Island Red D Plymouth Rock

11 A good layer has a:
A heavy body B dry vent
C soft abdomen D warm comb

12 The brooder equipment used in concentrating heat on the chicks is known as a:
A hover B chick guard
C thermometer D lamp

13 Which one of the following is an example of the semi-intensive system of poultry keeping?

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A deep litter B battery cage
C fold unit D free range

14 Which poultry disease is characterised by the sick bird tucking its head under a wing?
A Newcastle disease B coccidiosis
C pullorum D Gumboro disease

15 The average gestation period for pigs is:
A two months, two weeks and two days
B three months, three weeks and three days
C four months, four weeks and four days
D five months, five weeks and five days

16 Which of the following diseases affect pigs?
A conjunctivitis B coccidiosis
C brucellosis D rinderpest

17 A young female pig is called a:
A gilt B bunny
C cub D sow

18 Which of the following pig husbandry practices stimulates multiple births in farm animals?
A steaming-up B identification
C flushing D creep feeding

19 Kindling in rabbits can also be referred to as:
A lambing B kidding
C farrowing D littering

20 Which of the following terms describes a group of rabbits?
A hutch B colony
C rabbitry D flock

21 a) Explain the term breeding.
b) List four criteria used in selecting a breeding stock of animals.
c) State five objectives of animal breeding.

22 a) Name two exotic and two local breeds each of cattle, sheep and goats.
b) What are the main distinguishing features between:
(i) beef cattle and dairy cattle
(ii) sheep and goats?

23 a) Why are cattle mostly reared in the Guinea savannah zones of West Africa?
b) State the importance of each of the following husbandry practices:
(i) dehorning
(ii) castration
(iii) identification.

24 a) What are the advantages of rotational grazing?
b) Describe the preparation of hay.
c) State five differences between hay and silage.

25 a) What is the importance of colostrum in calf, kid and lamb rearing?
b) What are the symptoms of and control measures for trypanosomiasis?

26 a) What is zero grazing?
b) List two advantages and two disadvantages of zero grazing.

27 a) Explain artificial insemination.
b) Give two advantages of artificial insemination in animal production.
c) State two signs of heat in ruminants.

28 What are the main features of a good laying hen?

29 a) How does a poultry farmer prepare to receive day-old chicks?
b) Discuss briefly the management of brooder house temperature.

30 a) In what ways is the battery cage system of poultry keeping better than the deep litter system?
b) Why are exotic breeds of fowl preferred to local breeds for commercial poultry production?

31 Explain the meaning and purpose of the following:
a) culling
b) debeaking of chickens.

32 a) Give three causes of piglet anaemia.
b) Explain how piglets are cared for from birth to weaning.
c) Name four diseases of pigs.

33 Discuss the rabbit disease ear mange under the following headings:
a) cause
b) symptoms
c) treatment.

34 Describe the following husbandry practices in rabbit keeping:
a) breeding
b) feeding
c) handling.

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1 Nuclear energy

Learning objectives

After studying this unit, you should be able to:

1 describe the nature of radioactivity
2 describe the nature and uses of radioisotopes
3 state the uses of nuclear energy
4 outline ways for protecting people from the effects of radioactivity
5 outline the problems associated with disposal of nuclear waste.

Background information

Urbanisation and industrialisation have heightened the enormous and urgent need for electricity. Developed and developing nations are making frantic efforts aimed at diversifying their quest for cheaper energy sources.

Nuclear energy has provided assurances for nations that have human and material resources to utilise nuclear sources of energy. This energy, though dependable, has on its trail risky and potentially dangerous considerations, such as leaking of radioactive substances and the management of its waste products. Both have fatal consequences.

Humanity needs energy for economic activities and domestic needs. Nuclear energy is a reliable source of energy which many industrialised countries have adopted to meet their needs.

On the other hand a radioactive substance that is not effectively managed can have fatal consequences to living things and the environment for a considerable period.

Radioactivity

Radioactivity emanating from the disintegration of an unstable nucleus results in the formation of smaller nuclei. Alpha (α) and beta (β) particles and gamma (γ) rays are released.

The alpha particle is made up of a helium nucleus. The beta particle is a fast moving electron. Gamma rays are a form of electromagnetic wave with a very short, penetrating wavelength – much shorter than X-rays. Table 4.16 contains more detail about the charges and their effects.

Table 4.16 Alpha (α), beta (β) and gamma (γ) charges and their effects

Name	Nature of radiation	Penetrating power	Effect of magnetic field
alpha (α)	helium nucleus	slight	deflated charge
beta (β)	fast moving electron	greater than that of alpha	deflated charge
gamma (γ)	electromagnetic wave	greater than that of beta	no effect

Natural radioactivity occurs spontaneously in radioactive substances. The radioactivity process can also be induced by **irradiation** with other particles such as neutrons. Such a process is referred to as **artificial radioactivity**. In 1919 Rutherford used alpha particles to bombard nitrogen and produced protons. In artificial radioactivity, scientists found that because electrons with negative charges surround the nucleus of an atom, it is difficult to score an easy hit at the nucleus – there is repulsion between the particle and the electron charges. However, it is possible to hit the nucleus with a neutron, as this is an uncharged particle.

Both natural and artificial radioactivity decreases within a span of time, in a process known as **radioactive decay**. The period taken by a radioactive substance to decay to half its initial value is known as the half-life ($t_{\frac{1}{2}}$).

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The half life varies in different radioactive substances and is constant. The decay process is described by the relation $dN/dt = -\lambda N$ where N is the number of atoms. The disintegration rate depends on the atomic number of the radioactive nuclide.

ACTIVITY 1 Investigating the harmful effects of radioactivity

1 Alpha, beta and gamma radiation are sometimes referred to as ionising radiation.
   a) Find out what is meant by the term 'ionising radiation'.
   b) Explain why ionising radiation can be a danger to health.

Nature and uses of radioisotopes

Nature of isotopes

Atoms with the same number of protons and electrons occupy the same position on the periodic table and are atoms of the same element. If the number of neutrons varies in otherwise similar atoms then they are referred to as **isotopes** of the same element.

Hydrogen, for example, has three isotopes all having one proton – hydrogen-1 has no neutron; hydrogen-2, also called deuterium, has one extra neutron; and hydrogen-3, also known as tritium, has two extra neutrons.

Most isotopes occur naturally while others are artificially triggered. For any single isotope of an element, the sum of the protons and the neutrons is the **mass number** or **nucleon number**. This is always integral. For naturally occurring elements, the **average mass number** of its isotopes may not be integral. For example, chlorine is made up of two isotopes, one with a mass number of 35 and the other 37. 75 per cent of the isotopes have a mass number of 35, and 25 per cent have a mass number of 37, giving chlorine an average mass number of 35.5.

The average of the masses of a chemical element's naturally occurring isotopes is referred to as its **relative atomic mass**. The term **nuclide** is used to describe atoms of specific mass number.

Radioisotopes

Radioisotopes are isotopes which are radioactive; they can be produced in a nuclear reactor. Radioisotopes emit radiation such as alpha, beta and gamma rays. Most are artificially produced but all natural isotopes of atomic mass 210 and above are radioactive.

A nuclear reactor is a specially built enclosure in which controlled nuclear fission (see 'Nuclear energy and its uses') reactions take place. Artificial radioisotopes are produced by bombarding stable atoms or nuclides with fast moving neutrons. One or two neutrons are absorbed into the nucleus of the stable atom increasing the number of neutrons. A nucleus with an excess of neutrons is formed, making it unstable and as a result a radioisotope of the atom is formed. Such isotopes are used to provide the power for the batteries of heart pace makers, space craft and other scientific apparatus.

Uses of radioisotopes

Radioisotopes are used extensively in fields of medicine, industry, agriculture, radioactive dating and in electric energy production.

Medicine

Gamma rays are utilised in the medical field for the treatment of cancer (see Figure 4.40). Gamma rays from cobalt-60 are used to kill tumours and other cancerous tissues. Gamma radiation is also used in the sterilisation of surgical instruments. In addition, radioactive iodine-131 is used in investigating defects of thyroid glands.

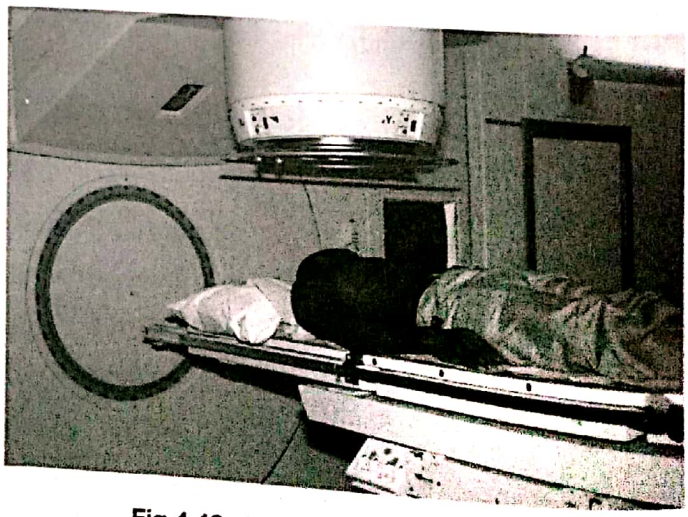


Fig 4.40 Treatment by radiotherapy.

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Industry

In industry gamma radiation is used to examine castings. Radioactive **tracers** are used to search for wear and tear in machinery and detect leaks in pipes.

Agriculture

Radiation helps produce a high-intake of crops, disease and weather resistant varieties of crops, to study how fertilisers and insecticides work, and to improve the production and health of animals. In the field of agriculture tracers are used to obtain information about plant and animal nutrition. Gamma radiation is used to sterilise male insects such as tsetse flies, to reduce the harmful insect population.

Food preservation

In food preservation radioisotopes are used to stop the sprouting of root crops after harvesting, to control pests and parasites, and to control the ripening of stored fruits and vegetables.

Radioactive dating

Analysis of radioisotopes is used by geologists, anthropologists and archaeologists in determining the age of rocks, wood and other materials. The carbon dating technique makes use of the fact that radioactive carbon-14 decays at a constant rate.

ACTIVITY 2 Write the structures of the stable isotopes of some radioisotopes

1 Complete a copy of the following table with the nuclides of the stable isotopes of the elements whose radioisotopes are shown in the left-hand column. Use the periodic table in Appendix III to help you.

Radioisotope	Stable isotope
$^{14}_{6}C$	$^{12}_{6}C$
$^{3}_{1}H$	
$^{32}_{14}P$	
$^{24}_{11}Na$	
$^{131}_{53}I$	
$^{60}_{27}Co$	
$^{239}_{92}U$	
$^{140}_{57}Ba$	

2 Explain briefly why each radioisotope can be unstable or radioactive.

ACTIVITY 3 Learn more about nuclear energy

1 Your teacher will show you charts or film of the useful and harmful effects of nuclear reactions.

2 In a separate lesson, debate the following proposition:

'Continued use of nuclear energy is a threat to the survival of plant and animal life.'

Nuclear energy and its uses

Under the right conditions, the nuclei of atoms of certain isotopes can be broken into smaller nuclei in a nuclear reaction. This process is called **nuclear fission**. In other instances light or small atoms come together to form heavier atoms, and this is called **nuclear fusion**. During both processes a small amount of the mass of the atom is converted into energy. This is **nuclear energy**.

Nuclear reactions release enormous amounts of energy. Nuclear fission occurs under high temperature when the kinetic energy of nuclides makes it possible to overcome the repulsive forces. This results in the contraction in the mass, which in turn releases an enormous quantity of energy which can be tapped for use. Figure 4.41 illustrates nuclear fission.

In nuclear fusion, the nuclides fuse together to form a single nucleus of greater binding energy per nucleon. This further results in the release of energy in an uncontrollable, violent way, releasing gamma radiation and enormous heat and shock waves. The strong light radiation and heat energy from the sun is the result of nuclear fusion reactions between hydrogen atoms.

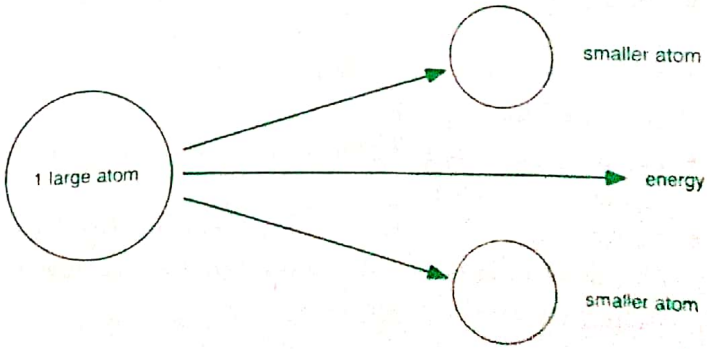


Fig 4.41 Nuclear fission.

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In a **nuclear power station** nuclear fission is carried out in a controlled way to produce a steady flow of energy to heat water into steam. The hot steam is used to turn turbines connected to a generator to produce electricity. The fuel used in most nuclear power stations is the isotope uranium-235. The fuel rods contain about three per cent uranium-235.

When nuclear energy is produced in an uncontrolled way, the result is a **nuclear explosion**. This can be brought about by an atomic bomb. An atomic bomb needs almost pure (100 per cent) uranium-235. Plutonium-239 is also used for producing nuclear energy and atomic bombs. Atomic bombs are extremely destructive devices and they also cause serious world-wide pollution. In August 1945, two atomic bombs were dropped on the Japanese cities of Hiroshima and Nagasaki. A great deal of plant and animal life was destroyed and descendants of people who were affected by the fallout then are still suffering after-effects to this day. Accidental leaks and explosions at nuclear power stations are also very dangerous.

Nuclear reactions and nuclear energy can also be used for peaceful purposes. The Ghana Atomic Energy Commission (GAEC) is responsible for the management of Kwabenya Reactor Project near Kwabenya village, about 16 km from Accra. The project uses a research nuclear reactor named Ghana Research Reactor – 1 that generates nuclear radiation for peaceful purposes. It uses low-level radiation for the following:

- preservation of food – by killing insects and micro-organisms that feed on and spoil the food
- pest control – the pests are sterilised so that they cannot reproduce
- plant breeding – different combinations of genes are produced which give higher yields in plants such as maize
- sterilising surgical equipment and needles for injection
- diagnostic scanning – to detect defects and diseases such as cancer in the body, for example head scanning at Korle Bu Hospital
- radiotherapy – to kill cancerous tissues in the body at Korle Bu Hospital
- radioactivity detectors – detection of legal and illegal trafficking of radioactive material that may be harmful at the harbours and ports.

Protection from the effects of radioactivity

Radiation hazards

Ionising radiation, in spite of its beneficial applications, is extremely dangerous to organic materials including humans. An exposure of humans to radiation ultimately may result in cancer. Heavy doses of radiation into the human body trigger radiation sickness and even death. Also, the structure of living cells can be altered by nuclear radiation, resulting in genetic damage to the organism. Such changes in the cell can hardly be noticed but can be detected in deformity of the offspring of the affected.

In using nuclear substances for industrial, medicinal or other purposes the following precautions are essential:

- use remote-controlled tools
- wear protective clothes (prescribed for the purpose)
- use shields
- stay a long distance from radioactive substances
- keep exposure time of the body to the radioactivity as short as possible
- have regular health checks.

Despite concerns, it is generally safe to live near to well run nuclear power stations, although when accidents occur the effects can be widespread and severe, such as at Three Mile Island in the USA in 1979 and Chernobyl in Ukraine in 1986.

Disposal of nuclear waste

Nuclear waste causes many hazards to humans and animals. There are two types of waste: low level and high level.

Low level waste includes contaminated protective clothing, discarded tools and other equipment used in nuclear reactors, such as water and air filters. **High level waste** includes the following:

- nuclear power plant that is disposed of
- spare parts from nuclear plant
- residue from radioactive substances.

Nuclear waste can remain radioactive for several millions of years and is extremely hazardous. Waste from nuclear substances should therefore be buried in discarded deep mines or in deep seas in solid rock to

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provide protection against explosions. The geology of the area must be stable and not susceptible to seismic activities that could blow the radioactive substances to the surface of the Earth. Disposal sites must be far from settlements and ground water to avoid contamination. To ensure safety, warning signs should be erected at waste deposit sites.

Self check

For questions 1 to 8, choose the letter that refers to the correct option.

1 The nuclear binding energy of an atom is the energy needed to:
- **A** excite the atom
- **B** separate the nucleus
- **C** separate the nucleus from the atom
- **D** bind the nucleus to the atom

2 Which of the following are emitted from a radioactive substance without altering the mass number or atomic number of the substance?
- **A** protons
- **B** electrons and neutrons
- **C** protons and neutrons
- **D** neutrons

3 Which of the following statements about fusion is incorrect?
- **A** A hydrogen bomb is a fusion reaction.
- **B** The energy obtained from 10 g of fuel in fusion is greater than in fission.
- **C** When a heavy atom is split into smaller atoms it is called fusion.
- **D** A fusion reaction can be controlled.

4 Which of the following substances is radioactive?
- **A** uranium
- **B** hydrogen
- **C** lead
- **D** lithium

5 The nucleus of an atom is composed of:
- **A** electrons
- **B** protons
- **C** protons and neutrons
- **D** electrons and protons

6 Which radiant emission can be used to examine cracks in casting?
- **A** alpha
- **B** gamma
- **C** X-ray
- **D** beta

7 In which industry is gamma radiation used to control the population of insects?
- **A** health
- **B** agriculture
- **C** environmental protection
- **D** industrial research

8 What does carbon dating involve?
- **A** the application of carbon-14
- **B** the use of gamma radiation to sterilise insects
- **C** the use of tracers to detect cancer
- **D** calculation of the number of carbon isotopes

9 **a)** State three peaceful uses of nuclear energy.
b) Explain briefly how nuclear energy is used in Ghana.
c) Describe briefly two ways in which nuclear radiation is a health hazard.

10 Explain the following terms:
a) nucleus
b) isotopes
c) half-life
d) radioactivity.

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2 Electronics

Learning objectives

After studying this unit, you should be able to:

1 investigate the effects of combining two transistors and the uses of the combinations.

Background information

Transistors are semi-conductor devices, commonly used to amplify signals or act as switches. The amplification effects of transistors are enhanced when they are effectively combined in pairs.

Combination of transistors

The amplification effect of transistors is enhanced when a proper combination of two NPN transistors are arranged in a special circuit called a **Darlington pair**. Amplification is also magnified by a combination of an NPN and a PNP transistor in another circuit called a **complementary pair**.

Darlington pair

The Darlington pair is made up of two transistors connected together to form a single unit. In the Darlington pair, the emitter of an NPN transistor is connected to the base of the other NPN transistor. The collectors of the transistors in the circuit are also connected together as in Figure 4.42.

In a Darlington pair the current applied to the base is enhanced by the second transistor. A very high current gain results and the signal is amplified to twice its original value.

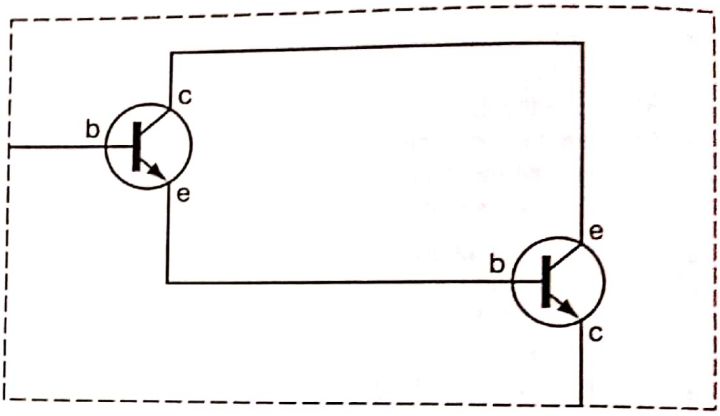


Fig 4.42 Darlington pair.

ACTIVITY 1 Exploring the Darlington pair in an amplifier circuit

Materials needed: An amplifier circuit with a single transistor; a Darlington pair; a loudspeaker.

1 Connect a simple amplifier circuit as in Figure 4.43.
2 Close the switch and record the sound from microphone as high or low.
3 Construct a Darlington pair with two NPN transistors.
4 Replace the single transistor in the circuit with the Darlington pair.
5 Compare the sound from the microphone with that of the single transistor. Give reasons for the differences in the sounds recorded.
6 Connect a loudspeaker to the circuit and test the amplifier. What do you observe?

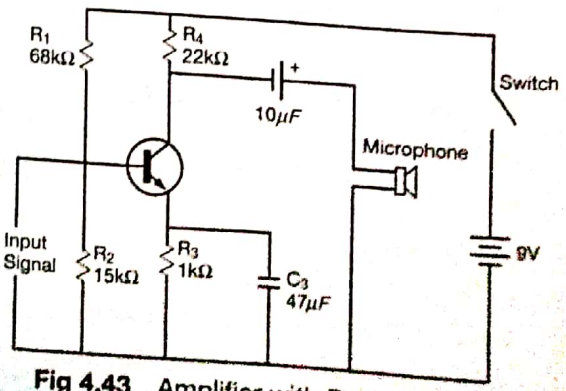


Fig 4.43 Amplifier with Darlington pair.

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ACTIVITY 2 Making a lamp that can be switched on and off by a key

1 Use flexible wire to make a circuit as in Figure 4.44.

2 Switch the key on and off and record your observation about the bulb.

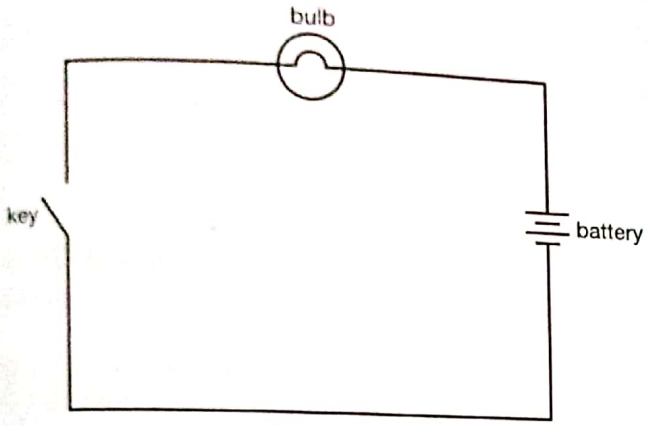


Fig 4.44

ACTIVITY 3 Using a transistor as a switch in a simple electronic circuit

1 Use flexible wire to make a circuit similar to that in Activity 2, but replacing the key with a transistor as in Figure 4.45.

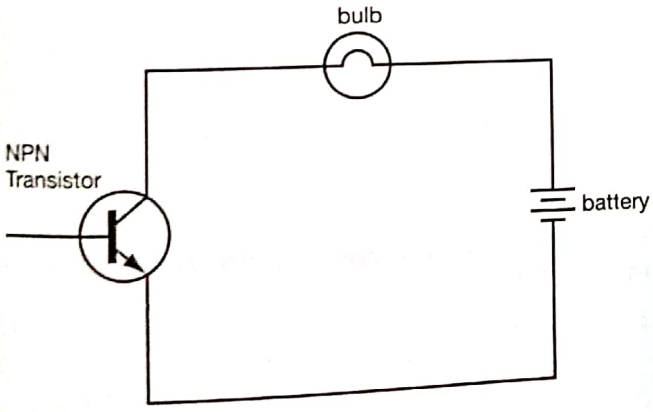


Fig 4.45

2 Record what you observe about the glow of the bulb and compare with the circuit in Activity 2.

3 Construct another circuit with a PNP transistor as in Figure 4.46.

4 Record what you observe about the glow of the bulb and compare with the other circuits observed. What role do transistors play in the circuit?

5 Use the concepts of forward bias and reverse bias learnt in JHS Year 2 to explain what happened in the activities.

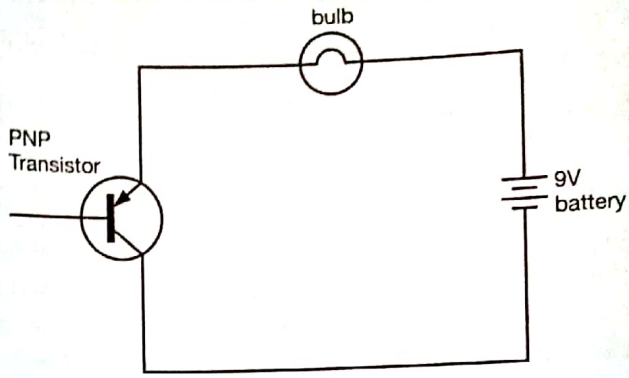


Fig 4.46

You might have deduced from the activities that the type of transistor used does not matter, provided it is placed in the circuit in such a manner that correct **junction biasing** (electron flow going against the transistor symbol arrows) is obeyed.

It is clear that there must be a component that can provide a base current or else the base current will always be zero (and the lamp will always be off). For an NPN transistor, base current must consist of electrons flowing from an emitter to the base.

ACTIVITY 4 Using a transistor and a switch in a simple electronic circuit

1 Connect a key to the base and the collector wires as in Figure 4.47.

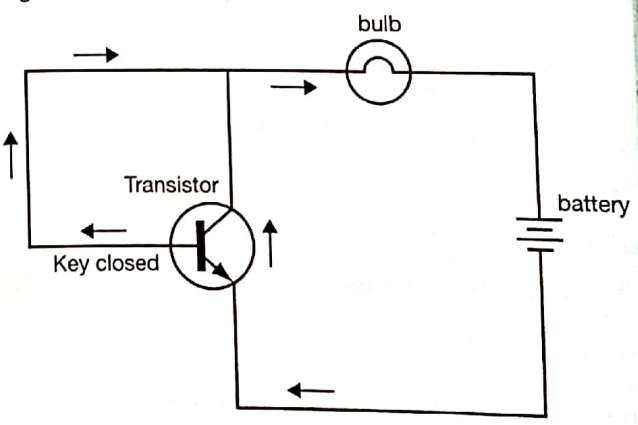


Fig 4.47

2 When the key or switch is closed, electrons flow from the emitter through the base of the transistor, through the switch and up to the left side of the bulb, back to the positive terminal of the battery. What happens when the switch is open?

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The activities help us to consider two important issues:

- Used in this way the switch needs to handle only a little base current to turn the transistor on.
- The transistor controls the bulk of the current that flows into the bulb.

In this way a small switch with low current rating can take care of relatively high current load. Also there is an added advantage of the current controlling the behaviour of a transistor, which can help to handle heaters or solar cells that utilise high current flow for their function.

Let us introduce an amplifier and a speaker in place of the bulb and discuss the effect it produces.

ACTIVITY 5 Investigating an arrangement of an amplifier and a speaker in a transistor controlled electronic circuit

1 Connect a 9V battery to a transistor, an LED, an amplifier and a microphone or loud speaker, as in Figure 4.48.

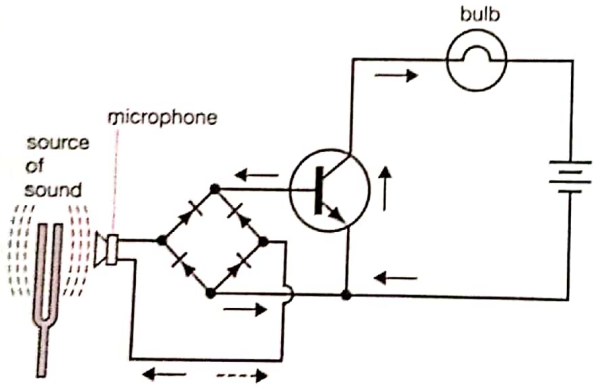


Fig 4.48

2 Switch the key on and off.

3 Observe and record the effect.

ACTIVITY 6 Exploring the transistor as a switch

1 Connect a transistor as a switch in a circuit as shown in Figure 4.49.

2 Record your observations.

3 *Work in groups* to discuss the role of the transistor in the observation.

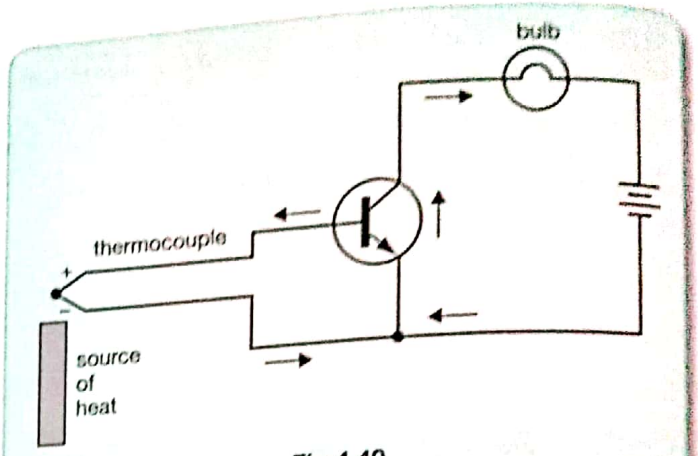


Fig 4.49

Complementary pair

In a complementary pair the emitter of an NPN transistor is connected to the emitter of a PNP transistor as in Figure 4.50.

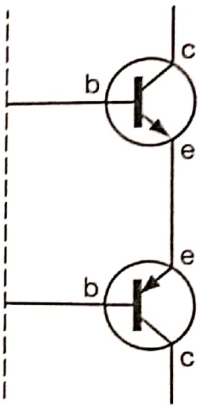


Fig 4.50 A complementary pair.

ACTIVITY 7 Investigating a complementary pair in an amplifier circuit

1 Connect the circuit as in the Figure 4.51.

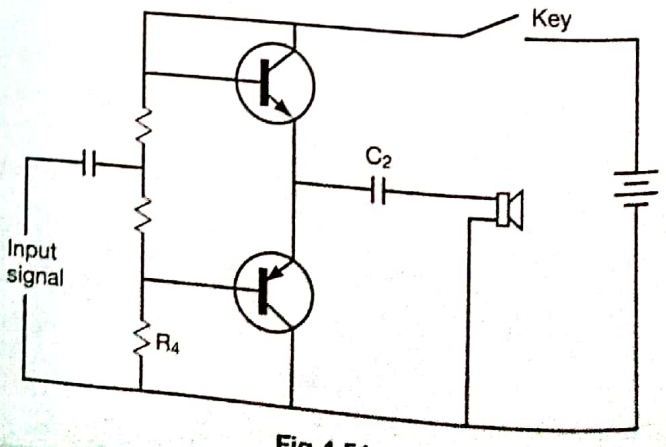


Fig 4.51

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2 Connect one PNP transistor to another NPN transistor from their emitters to form a complementary pair.

3 Connect the circuit to an amplifier unit as shown in the figure.

4 Record the quality of the sound produced.

5 What lessons do you learn from the circuit about a complementary pair?

PROJECT

Design and construct an amplifier using your knowledge about the Darlington pair and the complementary pair.

Self check

1 List the three applications of a transistor in an electronic circuit.

2 What is meant by the following?
   a) forward biased circuit
   b) reversed biased circuit

3 Draw the symbol for a transistor and show the parts.

4 What is the difference between NPN and PNP transistors?

5 Explain the following terms in an electronic circuit:
   a) emitter
   b) collector
   c) base.

6 Draw an electronic circuit to demonstrate a transistor as an amplifier of sound signal and show a device in which sound amplification is applied.

7 What is the role of the Darlington pair in amplification of sound signal?

8 How would you identify an NPN transistor from a PNP transistor in an electronic circuit?

9 Draw an electronic circuit to show a complementary pair of transistors.

10 List two gadgets that use the Darlington pair connection in their function.

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1 Work and machines

Learning objectives

After studying this unit, you should be able to:

1 explain work, energy and power
2 identify simple machines
3 explain the terms mechanical advantage, velocity ratio and efficiency of machines
4 explain the effects of friction and methods of reducing friction in machines.

Background information

The great advances made in civilisation would not have been possible without the invention of various machines that make it possible to convert one form of energy into another. The study of machines requires a clear understanding of the principles behind their operation and an appreciation of their function.

Work, energy and power

To be able to do work, a system must possess **energy**. The main source of energy for the Earth is the sun, which is the nearest star to the Earth. The other stars are so far away that very little of the energy they emit reaches the Earth; at best we see only a faint twinkling of light. On the sun a continuous nuclear reaction generates the heat and light energy that radiates into space around it, bathing the Earth and the other planets. If we use a magnifying glass to focus sunlight onto a sheet of paper the image of the sun on the paper looks very bright (evidence that it is light). It is hot enough to burn or char the paper (evidence of the heating effect).

Apart from the sun, we can obtain heat and light energy from incandescent objects such as fires by burning fuels. We can generate electricity from burning fuels, from nuclear reactors and from hydroelectric dam generators.

Energy shows itself in a variety of ways. We call these different **forms of energy**, because this helps us to explain what energy does in different contexts. Two important forms of energy are potential energy and kinetic energy.

Potential energy is the energy that a body or a system has because of its position or its condition.

Kinetic energy is the energy that a moving body has because of its motion.

For example, water stored up behind a dam has potential energy. When it is allowed to flow, this energy is converted into kinetic energy. A bow pulled ready to shoot an arrow has potential energy. When the arrow is released, this energy is converted into the kinetic energy of the arrow. A rock on a hill has potential energy, which is converted into kinetic energy, plus sound and heat, when it rolls down the hill. The rock may knock other rocks and stones and thus lose its kinetic energy.

The kinetic energy of a river can turn a paddle or a turbine. This in turn can generate electricity, thus converting kinetic energy to electricity. The wind is air that has kinetic energy. It fills the sails of boats and carries the boats sailing on the river or sea.

Other forms of energy are:

- **heat**, which produces a change in temperature or change of state of a material
- **light**, which is due to radiation of electromagnetic waves at frequencies to which the eye is sensitive
- **electricity**, which is produced when electric charge moves around a circuit

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- **nuclear energy**, which is produced by changes to the nucleus of atoms
- **chemical energy**, which is produced in a chemical reaction
- **sound**, which is caused by the vibrations of elastic objects in contact with air, producing waves in the air to which the ear is sensitive.

Potential energy and kinetic energy are two forms of mechanical energy, and we shall consider them in detail in this unit. The other forms of energy are discussed elsewhere in this book.

Work

Energy is transformed from one form to another when work is done:

> Work done = energy transferred

Here are some examples:

- **light bulb** – electric energy → heat + light
- **car engine** – chemical energy in the fuel → kinetic energy + heat + sound
- **television set** – electrical energy → light + sound + heat
- **candle** – chemical energy → light + heat

All such devices generate unwanted forms of energy while they are doing work: heat from the light bulb and television set, and sound from the car engine.

If a body is already in motion a force is required to bring it to a stop. In many cases this force, the braking force, is provided as friction by brakes. The work done results in the production of heat in the brake cylinders and brake bands.

Work is done when a force moves its point of application through a distance.

> Work done = force × distance moved in the direction of the force

Both energy and work are measured in **joules**. One joule of work is done when a force of one newton moves through a distance of one meter.

If the point of application moves in a direction at right angles to the direction of the force, no work is done by that force.

For example, to lift a weight of 100 N a height of 1.75 m from the ground to balance it on your head requires 100 × 1.75 = 175 J of energy. To carry this load 400 m along a level track gives it no more energy, as the distance moved is now at right angles to the weight.

Interconversion of energy

In a machine, one form of energy is converted into other forms of energy. The **law of conservation of energy** states:

> During a conversion, energy is neither created nor destroyed. The total amount of energy output is exactly equal to the energy input.

We can use a simple pendulum to demonstrate the conversion of one form of energy (potential) into another form (kinetic).

ACTIVITY 1 Investigating the conversion of energy from one form to another

1 Collect a pendulum bob on a string from your teacher.

2 Swing the pendulum bob on the string.

3 Note that when the bob is at its lowest point, it moves at its maximum speed, and it stops moving at its highest point.

4 What forms of energy does it possess at its highest point and at its lowest point? See Figure 4.52.

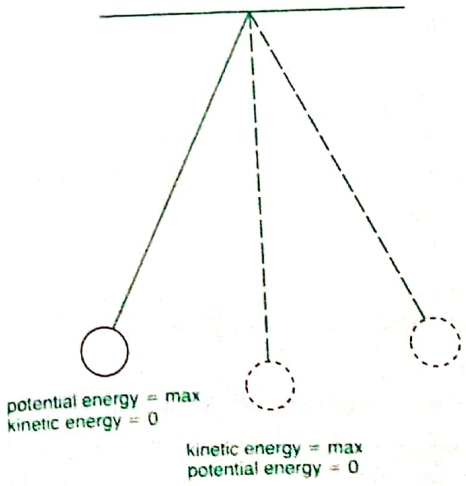


Fig 4.52 Investigating energy conversion.

In a swinging pendulum the pendulum bob has its maximum potential energy when it is farthest from its

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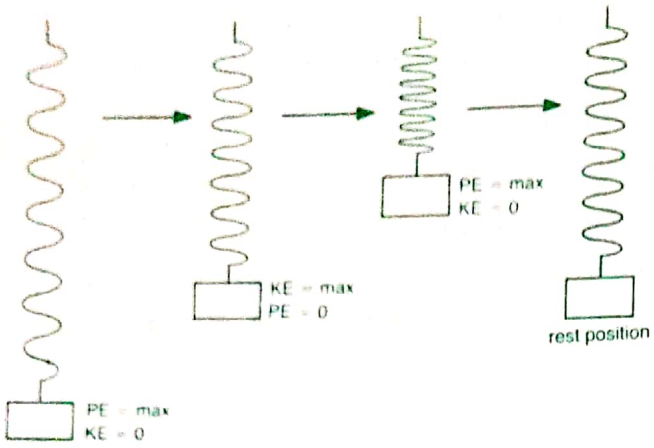


Fig 4.53 Kinetic and potential energy of a mass on a spring.

mean position. This potential energy is converted into kinetic energy as the pendulum swings, reaching its maximum kinetic energy as it passes its mean position.

If we hang a mass on a spring and set it in motion, it moves up and down (Figure 4.53). The potential energy in the mass/spring system has two components. The **gravitational potential energy** of the mass increases as it rises, and the **elastic potential energy** stored in the spring increases as the spring is stretched. The combined potential of these two added together is greatest when the mass is at the highest and lowest points of motion. At these points the kinetic energy is zero as the mass stops moving. The kinetic energy of the mass is greatest when it passes through the mid position of the oscillation. At this point the spring is stretched just sufficiently to support the weight of the mass.

In both the swinging pendulum bob and the mass on the spring, motion consists of repeating cycles or oscillations. During each oscillation, potential energy is being transformed to kinetic energy and back to potential energy.

Power

The greater the energy, the greater the amount of work it can do.

Work can be done slowly or rapidly. The rate of doing work is called **power**. Power is the rate of converting energy from one form into others, and is measured in **watts**:

1 watt (W) = 1 joule per second (J s^{-1})

$$\text{Power} = \frac{\text{energy transferred}}{\text{time taken}} = \frac{\text{work done}}{\text{time taken}}$$

The power of a device that converts energy is often quoted in **kilowatts** (kW) or **megawatts** (MW). A kilowatt device converts 1000 J of energy from one form to others each second. A megawatt device works at the rate of 1 000 000 J each second. This is equivalent to 3.6×10^9 J of energy per hour. (At one time the power of engines was given in horsepower. One horsepower is equivalent to 746 W.) Table 4.17 shows some typical power ratings for everyday electrical appliances.

Table 4.17 Power ratings of electrical devices

Appliance	Power (watts)
light bulbs	40, 60, 100
refrigerator	100
radio	3
iron	750
kettle	1500

Simple machines

A machine is any device that allows work to be done more conveniently and more easily. Examples of machines include such simple devices as a pair of scissors, tin cutters, a staircase or a ladder.

Work is done on the device or machine and, in turn, the machine does work by moving the load. The force used to move parts of the machine is called the **effort**. The machine in turn provides a force to move or raise the **load**.

The **work input** to a machine is given by:

Work input = effort × distance moved by effort

The **work output** by a machine is given by:

Work output = load × distance moved by load

The **efficiency** of a machine is given by the ratio of work output to the work input:

$$\text{Effiency} = \frac{\text{work output}}{\text{work input}} \times 100\% = \frac{\text{load} \times \text{distance moved by load}}{\text{effort} \times \text{distance move by effort}} \times 100\%$$

The ratio of load to effort is called the **mechanical advantage** (MA).

The ratio of distance moved by effort to distance moved by load is called the **velocity ratio** (VR).

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It follows that:

$$\text{Efficiency} = \frac{\text{mechanical advantage}}{\text{velocity ratio}}$$

In practice the efficiency of a machine is always less than 100 per cent, but to simplify calculations it is usually taken as 100 per cent unless otherwise stated.

Types of machine include:

- levers
- inclined planes and wedges
- pulleys (and differential pulleys)
- the wheel and axle.

Levers

A lever has three main points:

- the **effort**, or the position where the effort is applied
- the **pivot** or **fulcrum** about which the lever turns
- the **load**, or the position where the output is located.

There are three classes of lever:

- In the **first-class lever** the pivot is between the effort and the load: for example, a pair of scissors or shears – Figure 4.54(a).
- In the **second-class lever** the load is between the effort and the pivot: for example a wheelbarrow or a nut-cracker – Figure 4.54(b).
- In the **third-class lever** the effort is between the pivot and the load: for example, a pair of pincers or a pair of tongs – Figure 4.54(c).

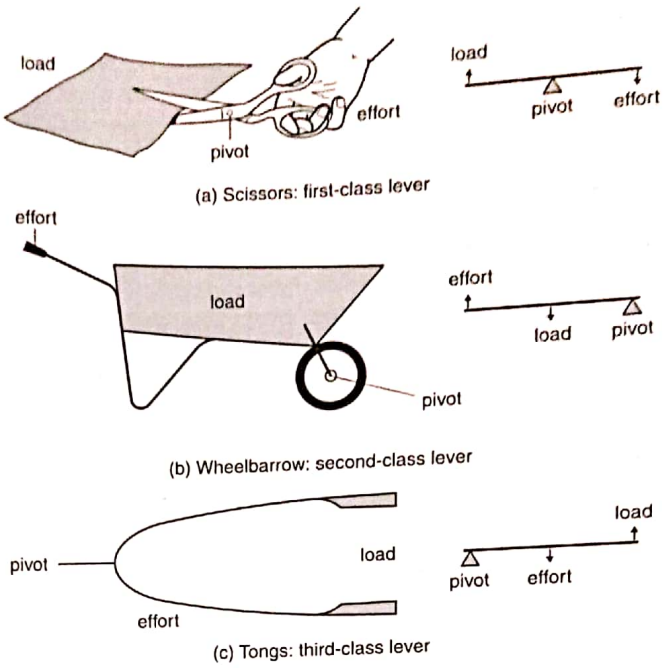


Fig 4.54 Levers.

Pulley systems

Using wheels called **pulleys**, very large loads can be raised using small efforts. To maximise their efficiency, the pulleys are made to work with the least possible friction.

A pulley system consists of a number of pulleys and strings. The simplest system has a single pulley. It works in a similar way to a first-class lever with 'arms' of equal length. The velocity ratio (VR) and mechanical advantage (MA) are both equal to 1. This is a machine that makes it possible to exert an upward force while pulling downwards. The change in the direction of the force applied is very convenient in many machines.

Adding a second pulley gives a system in which VR = 2 and MA = 2. The load is on the second pulley, which is carried by two strings – Figure 4.55(a).

Using three pulleys the load is carried by three strings – Figure 4.55(b); VR = 3 and MA = 3. Using four pulleys the load is carried by four strings – Figure 4.55(c); VR = 4 and MA = 4.

This sort of pulley system is called a **block and tackle**. As the number of pulleys in the system increases the overall efficiency decreases because of friction.

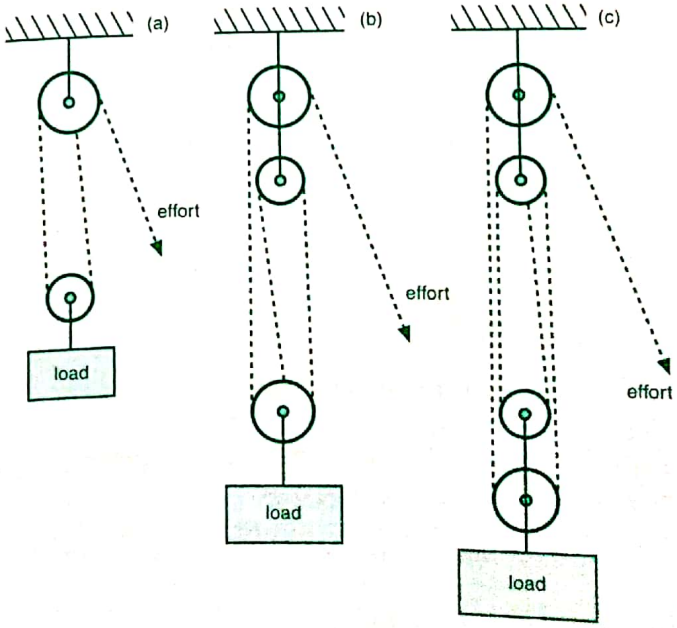


Fig 4.55 Block and tackle pulley systems.

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ACTIVITY 2 Investigating pulley systems

1 Collect from your teacher two pulleys in a block and one pulley, string about 2 m long, a stand, some weights and two metre rules.

2 Hang the two-pulley block on the stand and thread the pulleys, with the one pulley below to carry the load.

3 Pass the string over one of the pulleys above and tie a 50 g mass to the end of the string. This is the effort. Pass the string around the single pulley, over the second pulley below, and finally to the pulley above and tie it there.

4 Hang different weights on the pulley below, and find which weight balances the effort. This is the load.

5 Draw a table like this:

Effort	Load	Distance moved by effort	Distance moved by load	VR	MA	Efficiency = MA/VR

6 Repeat the experiment with two pulleys above and two pulleys below.

Wheel and axle

This is a pulley system that consists of one pulley and an axle. The radius of the axle, r, is smaller than that of the wheel, R (Figure 4.56).

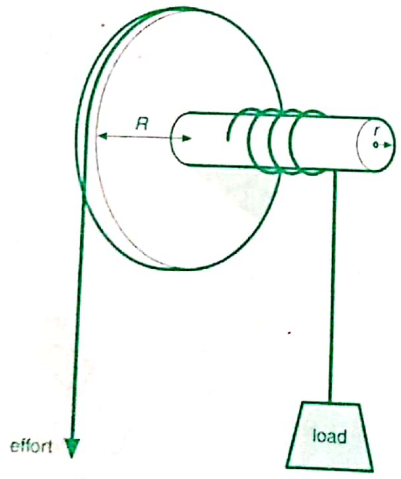


Fig 4.56 Wheel and axle.

For one rotation of the system the effort moves through $2\pi R$ and the load is raised by $2\pi r$.

$$\text{Velocity ratio} = \frac{2\pi R}{2\pi r} = \frac{R}{r}$$

$$\text{Mechanical advantage} = \frac{R}{r}$$

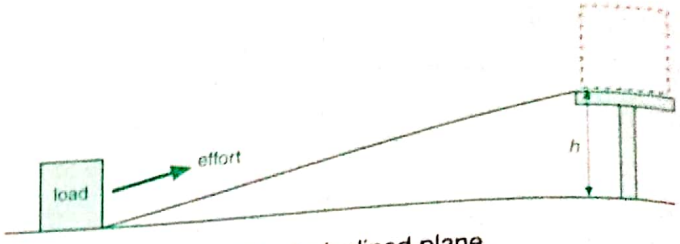


Fig 4.57 An inclined plane.

Inclined plane

Examples of this system include staircases, ladders, screws and wedges. In all these the load moves along the plane in such a way that, as the effort acts, the load moves up (Figure 4.57). The direction moved by the effort may be along an inclined plane or round a screw, where the distance is given by the pitch of the screw (the distance between two threads of the screw).

A road going up a mountain is made winding and circuitous so that the effort moves a long distance to raise the load (car and passengers) a short height.

In the screw-jack the effort turns a large circle while the load is raised by the pitch of the screw. The velocity ratio is very large and thus the mechanical advantage is also very large. However, the efficiency is much reduced because of friction. The same is true of a wedge. The axe is a wedge that also has a low efficiency because the frictional force is high.

Friction

The ideas of friction were first introduced in Year 2, Section 5, Unit 2. You may need to remind yourself about friction before reading this section.

Methods of reducing friction

We have already looked at friction in Section 5, Unit 2 and at the difference between static and dynamic friction., and the next activity demonstrates this difference, and looks at one way of reducing friction. Table 4.18 explores the advantages and disadvantages of friction.

ACTIVITY 3 To demonstrate friction, dynamic friction and reduction of friction

1 Collect the following from your teacher (or the teacher sets up the demonstration): a sliding block and weights, and rollers (such as round pencils).

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2 Arrange the experiment as shown in the diagram (Figure 4.58).

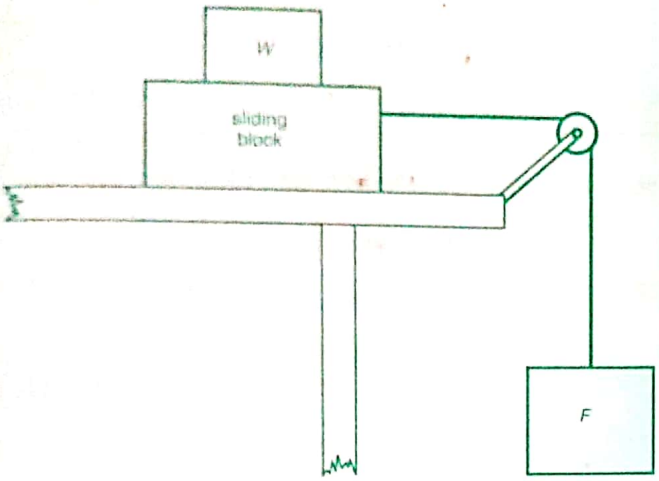


Fig 4.58 Friction apparatus.

3 Start with a 1 N weight (W) (a mass of 100 g) on the sliding block and hang weights (F) of 0.5, 0.6, 0.7 N and so on, until the block slides on the main block. Repeat to obtain a more accurate force that just starts the block sliding. Increase W and find F/W, which should be a constant (the **coefficient of static friction**).

4 Repeat the experiment but give the sliding block a slight push.

5 Now place the block on rollers and repeat the experiment starting with 0.05 N (i.e. 5 g) or less. Change W and find F under static conditions, dynamic conditions and the coefficient of rolling friction. Which friction is the least?

Table 4.18 Friction

Advantages	Disadvantages
1 It holds the feet and car tyres firm on the ground and prevents them from sliding.	1 It causes wear and tear to the feet, shoes and car tyres.
2 Friction enables the hand and machine parts to grip other bodies firmly.	2 It slows down motion especially where machine parts slide over each other.
3 Friction helps to produce light and fire when a match is struck against a match box and iron is struck against rock.	3 It overheats machine parts and leads to melting and cracks.
4 It enables vehicles to stop when brakes are applied.	4 It reduces efficiency in machines and dissipates energy.
5 It helps to grind food and machine parts into required shapes.	5 It leads to wear and tear.

It should be clear from Activity 3 that the lowest value of F/W is in rolling friction. In fact the frictional force is greatest in limiting static friction, less under dynamic friction, small in roller friction, and very small indeed using ball-bearings and under lubrication. Axles of wheels run on ball-bearings with oil lubrication. The oil gets between the moving parts, so keeping them slightly apart; this prevents the surfaces from wearing each other away, and also reduces energy loss as heat.

Self check

For questions 1 to 3, choose the letter that refers to the correct option.

1 A block and tackle pulley system has three fixed pulleys and two moving ones. What is the velocity ratio of the system?
A 2 **B** 3
C 5 **D** 6

2 The SI unit of work is the:
A ampere **B** joule
C newton **D** watt

3 Which of the following tools is a second-class lever?
A pair of tongs **B** bread knife
C claw hammer **D** nut-cracker

4 **a)** What is friction?
b) State two methods by which friction can be reduced.

5 **a)** What is required to be able to do work?
b) What is it that is produced by the sun and spreads in all directions from it? By what process is it produced?

6 The water on the cliff in a waterfall has _____, _____, which, when the water flows down over the cliff, is converted into _____, _____.

7 **a)** Work is measured in _____.
b) Energy can be neither _____ nor _____.

8 In what unit is the power of an engine measured?

9 The force input of a machine is called the _____. It does work on the _____. The ratio of the work output to the work input is called the _____.

10 **a)** Why is a 100 W lamp bulb brighter than a 60 W one?
b) How much electrical energy would be converted to other forms if a 100 W light bulb was left switched on for 3 hours?
c) If in this time 270 kJ of light was produced, how much energy would have been wasted as heat?
d) What is the efficiency of the light bulb?

11 A student is drawing a bucket full of water from a well. It takes 5 seconds to lift the bucket, which weighs 150 N, through a vertical height of 4 m.
a) What type of energy does the water in the bucket gain as it is raised?

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b) Calculate the work done by the student.
c) Calculate the power output of the student.

12 Which of the following may be considered to be machines?

crane hill hinges jaws swivel chair

13 The ratio load/effort is called the _____, _____. The velocity ratio of a machine is the ratio of the distance moved by the _____ to the distance moved by the _____.

14 a) In a simple pulley system the velocity ratio is equal to the _____ of strings that support the load.
b) In a four-stringed pulley system, how far does the effort move in order to lift the load a height of 12 cm?
c) What is the mechanical advantage of this pulley system, if the load weighs 72 N and the effort required is 20 N?
d) Find the efficiency of this system as a percentage.
e) Why is the efficiency less than 100 per cent?

15 a) A body sliding on a surface is stopped by a _____ force. This force is reduced by placing _____ between the sliding surfaces.
b) If it requires a force of 8 N to start a weight of 10 N sliding on a wooden board, what is the coefficient of static friction?
c) Estimate the force you think would be needed to keep it moving, and explain your choice.

16 A body moving in a liquid is opposed by the _____ _____ of the liquid. Friction is much _____ by using ball-bearings in pulleys, axles and wheels.

17 A hovercraft moves on a _____ of air. The vessel is pushed over the ground by _____. The air _____ the _____ between the ground and the craft.

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2 Endogenous technology

Learning objectives

After studying this unit, you should be able to:

1 distinguish between science and technology
2 outline the significance of science and technology to society
3 explain the term endogenous technology
4 outline problems associated with the application of some technology
5 identify some small-scale industries and their importance
6 identify the scientific principles underlying the operations of some small-scale industries.

Background information

Technology is as old as humanity. Tool making with hard stones, wood and bones were the first steps in technology. The stone tools were used mainly for hunting and cutting. Thousands of years later humans discovered the use of fire, metals and alloys. They then advanced to make tools and artefacts from metals such as iron, gold, silver and the alloy bronze.

Technology has developed through simple machines such as the *shadoof* in Egypt, the screw, lever, wheel and pulleys, to gears, bicycles, the printing press, steam engines, automobiles, aeroplanes, computers and beyond.

Technology also includes architectural structures such as the great pyramids of ancient Egypt and the geometric forms of buildings of the Greeks. Many technologies were applied in the construction of these structures.

Technology, like science and other disciplines, has developed through various stages to reach their present modern levels. New and improved technologies are introduced when required; some take a short time whereas others take longer times.

The desire to improve and adapt tools and machines to serve the needs of people gave rise to industrialised societies.

Two useful working descriptions of technology may be derived from its use in practice and the impact it has on society:

> **Technology** is the application of all the knowledge, creativity, skills and products available to society to improve the life and meet the needs of people.

> **Technology** comprises all the tools and products made by humans, their function or the work they do, their use, and all the effects and change that their application has on society.

Science and technology

Science can be defined in a number of ways. Science is the process by which people accumulate knowledge and skills in which they can place a high, and often measurable, degree of confidence.

Science is a continuous process of investigation and experimentation in order to widen people's understanding of the natural world. It involves the gathering and recording of knowledge to find answers to the questions and challenges that life poses every day. It also stems from the natural human traits of enquiry and creativity. There are many methods of collecting information and forming ideas, but methods used by scientists must be:

- systematic

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- objective
- reliable.

These methods are often referred to as the **scientific method**; see Year 1, Section 1, Unit 1.

There is a close relationship between **technology** and science in particular, and with many other disciplines or bodies of knowledge in general.

Many technologists relate the discoveries of scientists to **the needs of society**. They develop and apply scientific ideas to produce new materials, such as plastics to replace wood and metals, and tools and machines such as computers, aeroplanes and combined harvesters that work faster and more efficiently and reduce the use of human energy. New medicines such as antibiotics have helped in providing better health. Advances in scientific knowledge, human creativity and innovation have also improved agriculture, nutrition and forms of transport and communication. The technology of telephones, mobile or cell phones and internet services provide convenient, fast and easier modes of communication. Improvements in agriculture and biological systems (biotechnology) and many other fields have also improved quality of life and brought about modernisation of society compared with, for example, 100 years ago.

Our study of technology in this chapter will involve the ability to:

- be technologically literate – that is, to be able to read and write about simple technological practices
- be aware of and recognise technological developments
- appreciate technological changes and develop a basic capability to design, use, repair and maintain simple technologies in our daily lives.

The study should make us aware that every society has a technological history, with its indigenous tools adapted to suit its environment. With knowledge from its own society and others, the indigenous tools can be improved and new ones developed to improve the quality of life.

However, the use of science and other disciplines should help and encourage us to apply technologies in a humane and responsible manner to protect ourselves and our environment. In this way technology, at any level, will continue to serve our needs, but should not be allowed to be a source of woes or the means of our destruction.

Science, technology and the development of society

All humans, no matter where they are on Earth, have shown the ability to use and modify the resources of nature in their environment to live a better life. The pace of such development may differ from place to place. Africa is the home or origin of *Homo sapiens* (humans). Africa has been through various levels of scientific and technological developments and decline in her own way just as other societies have in other parts of the world.

Many societies in West Africa, including Ghana, can trace their origins to the eastern half of the African continent. Its people migrated over long distances to other settlements at different times in history. Along with the migration came various technological tools and technologies developed by those peoples to serve their needs and curiosities. The tools were developed where they settled at any time, during migration and at their present settlements.

The speed of development of traditional technologies was slow. There are various reasons for this:

- **Isolation** and long distance from the leading places of scientific and technological development prevented the learning and sharing of different technologies from other societies.
- There was an **inability to adapt** old, indigenous tools and create new ones to reduce physical labour, cost and time of production. This is particularly evident in agricultural tools production and technologies. It resulted in low levels of agricultural (food) output, which could not support the necessary, strategic, population growths, trade and the generation of wealth and capital.
- There was a long-term **dependence** on family and communal (community and small groups) ways of producing goods, without the introduction of machines and factories. This reduced the quantity of goods available for trade in other lands.
- There was a **low level of professional interest** in adopting better technologies from other societies. This took place at crucial times of technological development in other parts of the world, such as during the Industrial Revolution in Europe.

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- Knowledge tends to be preserved in **oral rather than in written form** in many African societies. This is obviously less reliable, and restricted to fewer people. Knowledge is invariably lost more easily in transmission from generation to generation or through disturbances such as war and migration.

In many areas, the development of indigenous technological tools was stifled by the arrival of superior tools with the Europeans.

Ancient indigenous tools such as the hoe, the cutlass, mortar and pestle are still used widely in Africa to produce the necessities of its people, even into the third millennium. Many more are imported from outside Africa, or produced in Africa using tools and machines that originate from outside the continent.

However, some indigenous technological tools and methods have been improved to make them more efficient. In Ghana they are often referred to as **intermediate** or **endogenous technology**.

The influence of technological tools and/or political governance from Europe has been with Africa since the fifteenth century. The cultural effect has been tremendous. Self-governance came mainly in the 1960s, but the influence of European and other foreign technologies continues to have a wide influence on African societies. Self-governing Africa still lags behind many other societies in the development of technological tools and technologies, for a number of reasons:

- the low level of scientific and technological investment, research and development (R&D)
- the lack of capital to venture into modern technological development, innovation and trade in tools and machines to compete in the global (world) market
- the poor rate of growth in economic and educational fields to keep pace with other countries outside Africa
- concentration on production of primary products such as cocoa and gold which fetch lower prices than tertiary or finished products.

Many tools and technologies have gone through changes and modifications. However, the rate has been slow compared with improvements in some other societies. The result is a big and widening gap in the quality of life between developing and developed countries. Two important steps that can help to bridge this technological gap are education and technology transfer.

Education

Education in general nurtures positive attitudes towards technological and scientific development in society. There is a vital need to acquire more scientific and technological knowledge and literacy.

This is done in both formal and informal educational institutions, from the lowest to the highest levels. The formal sector includes elementary, basic, secondary and technical schools, polytechnics and universities. The informal sector includes the research institutions and training centres for out-of-school learners, such as the Intermediate Technology Transfers Units (ITTUs) in Ghana. A certain minimum number of skilled workers will be produced to undertake and sustain scientific and technological development.

ACTIVITY 1 Finding out and discussing scientific principles and their application in technology

1 a) State at least four traditional or indigenous technologies.
   b) Give reason(s) why each is described as a technology and an indigenous one.
   c) Suggest the scientific principles by which each technology operates, and/or how the products are made.

2 a) State at least four modern technologies common around you.
   b) Give reason(s) why each is described as a technology and a modern one.
   c) Suggest the scientific principles by which each technology operates and/or how products of each technology are made.

3 Propose, with reasons, way(s) by which each traditional or modern technology can be modified or improved.

4 Select two students – preferably a boy and a girl – to discuss four selected technologies in class.

5 Arrange for an expert from outside the school to discuss one modern and one traditional technology, including effects of the technology on the environment.

ACTIVITY 2 Understanding how some traditional and modern technologies operate and their advantages

The following technologies, technological processes and products are listed in random order:

blender, leaf, wood bark, mill, telephone, gong-gong, animal hide, hoe, saw, cotton textile, animal-driven plough, nylon textile, polyester textile, grinding stone, refrigerator,

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fax machine, cellular phone, pestle and mortar, cutlass, mower, Morse code, 'coal pot', earthenware cooler, gas cooker, electric cooker, mechanical plough, chain-saw, microwave oven, cart, wheel, tripod fireplace, motor car, aeroplane, bicycle, space capsule, herbs, calculator, fingers, computer, medicinal tablets, medicinal capsules, fountain pen, ballpoint pen, printing machine.

1 a) List the technologies in groups according to the common service they can provide.
   b) Name the service provided by each group.

2 a) Arrange the technologies above in increasing order of their improvement.
   b) Briefly state the improvement from each technology to the next.

3 a) For each group state the latest technology or state-of-the-art product.
   b) Briefly state the improvements in the latest technologies that you might expect in the future.

4 Prepare a list of technologies, their products or processes for two more groups entirely different from those given above. Arrange the list in order of improvement in the technology.

5 *Work in groups.* Select two groups of technologies that include an indigenous one, e.g. refrigerator and earthenware coolers. Discuss the scientific principles applied or involved in the technologies.

Endogenous technology

Endogenous or intermediate technology is a relatively new term, used to describe a blend of local, indigenous technology with modern technology. Also referred to as appropriate technology, it is designed with special consideration to the environmental, cultural, social and economic aspects of the community it will serve. It typically requires fewer resources, is easier to maintain, is cheaper overall, and has less of an impact on the environment. Endogenous technology usually relies on labour intensive rather than capital intensive solutions.

There may be some problems associated with the development of endogenous technology in Ghana. For example, dependence on imports for new capital equipment may slow down development.

ACTIVITY 3 Discuss endogenous technology

Work in groups to discuss potential problems of endogenous technology development in Ghana.

Small-scale industries

Small-scale industries provide a vital source of employment and income for millions of people in Ghana and other African countries. They use mainly local resources or raw materials, or minimum input of materials and usually have a small market for their products. However, they promote the creation and use of local technologies and provide cost-effective skills training. Often they employ fewer workers with a low starting capital and use a low amount of energy compared with the large, modern industrial companies, such as gold and aluminium extraction outfits, which use sophisticated or the latest machines and employ a large number of workers.

However, small-scale industries also face unique problems, which affect their growth and profitability and hence make it harder for them to contribute effectively to sustainable development. These problems include lack of access to credit, inadequate managerial and technical skills, low levels of education, poor market information, no or weak research and innovation linkages and lack of access to technology.

The experience of Asian countries in the past three decades has shown that effective support for small-scale industry development can not only boost industrial output and exports, but also accelerate employment growth. Similar policies applied in African countries such as Ghana could result in the same sort of growth in output and employment. Soap making and edible oil extraction are two examples of traditional small-scale industries in Ghana that are now beginning to benefit from the introduction of intermediate technology, and both are looked at in detail below. Bread making and salt extraction are dealt with under the heading 'Scientific principles involved in operation of some industries'.

Soap making

Soap-making technology has been practised round the world since ancient times. Soap is one of the basic requirements of human beings. It is used for washing the body, for washing clothes and for cleaning other materials. It is manufactured on a small scale by traditional methods and on a large scale in modern factories.

Essentially, soap is produced by reacting a fat or oil with an alkali (either sodium hydroxide or potassium hydroxide). This process is called **saponification**. A better yield and quality of soap is produced by using a

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blend of fats and/or oils. For example, a blend of coconut oil and palm oil, or shea butter blended with fish oil or groundnut oil, gives a better quality of soap than any of the fats or oils alone. A fat or oil can be decolourised before the saponification process starts.

The main stages in the modern manufacture of soap are:

- saponification
- salting out to separate the soap from the glycerol
- repeated washing with water
- fitting – adding water and boiling the resulting mixture to give a uniform consistency
- drying.

See the flowchart in Figure 4.59.

Although traditional production methods have improved over the years, the quality of soap produced in modern factories is better because the crude, impure soap is purified to a higher degree. In the traditional methods only the first stage (saponification) is carried out. This gives a crude product, sometimes called **grained soap**. It can contain many impurities, including colouring and glycerol. Other impurities include excess alkali, such as ash particles, or excess oil, which can cause undesirable colour or odour, and itching of the skin.

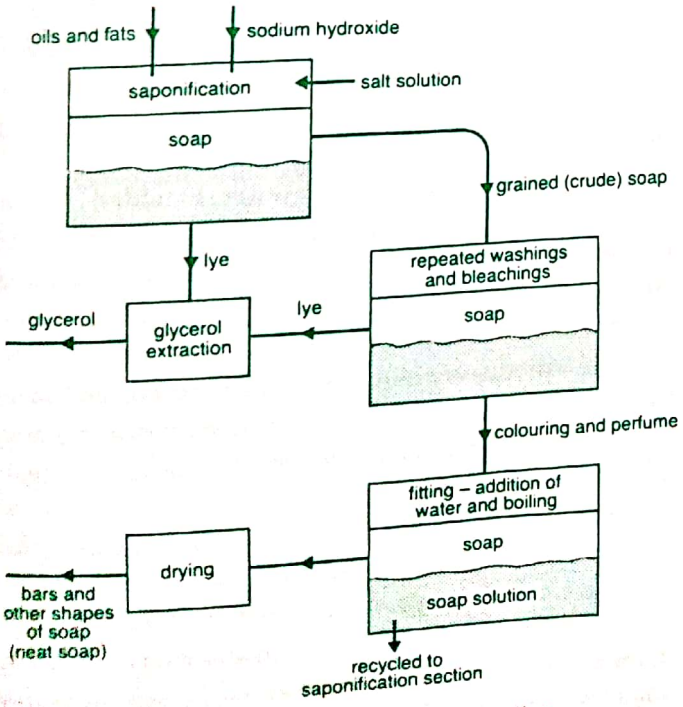


Fig 4.59 Flowchart of soap production.

In the industrial manufacture of soap, the aqueous solution containing glycerol is called **lye**. Pure **glycerol** is a thick, viscous, colourless fluid, commonly called **glycerine**. Its industrial uses include the manufacture of cellophane film, dynamite and cosmetics. The glycerol extracted from the lye is brown and impure. This crude glycerol could be one of the causes of the brown-black colour of some local soaps.

Salting out, using salt solution, separates the soap from the glycerol and some other impurities. Repeated washing and bleaching removes more glycerol, colouring and undesirable scent from the crude soap.

Soaps prepared with sodium hydroxide and mainly animal fats are called **hard soaps**. They are water-soluble, but are less soluble than soaps prepared by using the alkali potassium hydroxide. Potassium hydroxide soaps are called **soft soaps**; they are used mainly for bathing and other toilet purposes.

ACTIVITY 4 Visit to a local traditional soap factory

1 Visit the nearest indigenous soap factory.

2 a) With the help of the factory attendant or supervisor, record:
   (i) the raw materials used
   (ii) the main stages of the manufacturing process
   (iii) any purification process used in the manufacture.
   b) Collect some samples of soap and describe the colour, scent and hardness of each sample.

3 a) Draw a flowchart for the traditional soap production process.
   b) Suggest ways in which the colour, scent and hardness of traditional soap could be improved.

4 Suggest a chemical that could be used to bleach coloured oil or crude soap.

ACTIVITY 5 Preparing soap in the traditional way and comparing it with soap from a modern factory

Prepare soap in the traditional way as follows:

1 Dissolve about 500 g of plantain peel ash in clean water in a plastic container. Filter the solution through a clean cloth into another container of similar size. Feel the solution, and describe how it feels. What does your description indicate?

2 a) Pour about 100 cm^3 of palm oil into an open pot or tin can. Heat it to melt the oil.
   b) Pour the alkaline solution obtained in task 1 carefully into the hot palm oil and stir it continuously with a wooden spoon or stick. Boil and stir the mixture for some time, and then allow it to cool.

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c) Describe briefly how you would test whether the product is soap or not. Do the test.

3 a) (i) What is the colour of the soap?
(ii) Is it hard?
(iii) Describe its scent.
b) State ways in which you can remove undesirable
(i) colour
(ii) scent
from the soap.
c) State the main impurities in the crude soap prepared by the traditional method. Suggest a way in which you can remove them.

4 Take a small piece of the soap that you have prepared and rinse it thoroughly with an aqueous solution of sodium chlorate(I) (bleach) or sodium hydrogen sulphate(VI) in a clear glass container. Does the soap's colour change?

5 a) Cut small pieces of a toilet soap (e.g. Lux) and a laundry soap (e.g. Guardian) and compare them with the traditional soap produced in this Activity.
b) State the main additional process that the factory-produced soap has been through.
c) Write a brief report, including measures that you could take to improve the quality of the traditional soap.

Extraction of edible oils

Many fruits, vegetables and grains contain oil. Edible oil or cooking oil can be extracted from some of these plant sources. For example:

- palm oil (red in colour) is extracted from the red-coloured fleshy part or pericarp of the palm fruit
- palm kernel oil (light brown in colour) is extracted from the kernel contained in the hard shell of the palm fruit
- coconut oil is extracted from the white flesh within the hard shell of the coconut fruit
- groundnut oil is extracted from groundnuts.

Palm oil

The flow diagram in Figure 4.60 shows the traditional methods used in producing palm oil. The difference between the cold method and the hot method is in the way the fibre product is treated with cold and hot water to extract the palm oil.

Bunches of palm fruit are harvested from the tree and cut into chunks of the nuts. The chunks are sprinkled with water to enhance detachment from their stalks. The chunks are kept for three to four days to ferment. The fruits are then removed from the chunks. In order to prevent the formation of mould, the fruits may be dried in the sun. The fermentation and drying helps

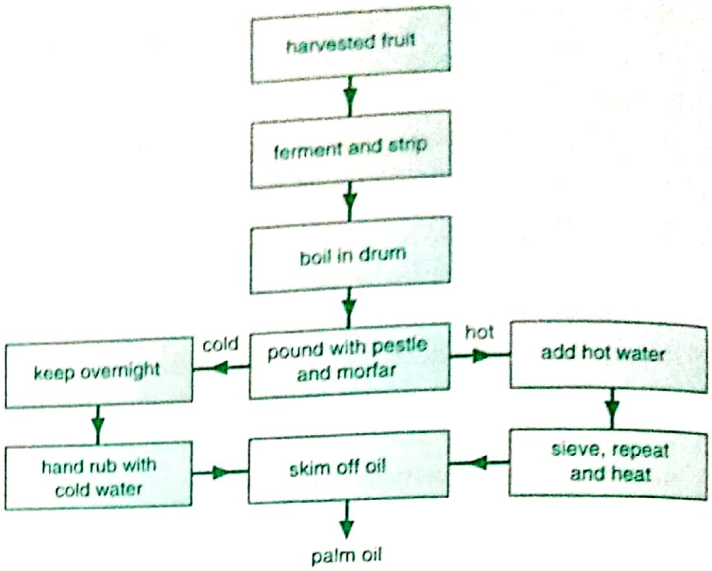


Fig 4.60 Flowchart for producing palm oil.

to soften the outer flesh (exocarp) and remove any bad taste due to mould.

The fermented fruit nuts are boiled in containers such as steel drums. To separate the fibrous part containing the oil from the hard palm kernel, the boiled nut is pounded well in a mortar with a pestle. The whole of the pounded mixture of nut fibres and water is poured into a basin.

In the **hot method**, hot water is poured on and stirred well. The mixture is then sieved into a container for boiling. The oil, mixed with the hot water, passes through the sieve as a slurry made up mainly of the palm oil, water and other particles. Finally the slurry is boiled until the red palm oil collects at the top of the mixture owing to its lower density. A pan is used to skim it off into suitable containers.

In the **cold method**, cold water is added to the pounded mixture. The mixture is hand rubbed well in an open pan until palm oil collects at the top. The palm oil is skimmed off, heated to boil and collected into suitable containers.

In both methods boiling removes water and enhances the taste and shelf life of the oil. Further heating with selected additives produces *dzomi*, a tastier and longer-life palm oil.

An important by-product of the process is the palm kernel, with its granite-hard shell and fibre. The palm kernel is cracked to separate the kernel and the hard shell. The palm kernel is used as the raw material for making palm kernel oil. The cracked nutshell and the dry fibre are used as fuels for firing and domestic heating.

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The main drawbacks in the traditional extraction methods are:

- the small quantity of palm fruit that a mortar can hold for pounding
- the tiresome pounding process
- the inefficient squeezing of the fibre containing the oil, and the sieving of the slurry; these are done without any applied pressure, which would increase the efficiency of the oil extraction.

In Ghana these drawbacks have been greatly addressed by the intermediate technologies developed by Agriculture Engineers Ltd, AGRICO and the Technology Consultancy Centre (TCC) of the Kwame Nkrumah University of Science and Technology, Kumasi.

The main features in the TCC improved technology compared with the traditional methods are:

- **larger-capacity palm fruit boiling tank** – this has a capacity $5\frac{1}{2}$ times that of the traditional container; it steams the palm fruits in a separate container, ready for pounding
- **motor-driven pounding machine** – this takes the place of the tiresome mechanical labour in the traditional method; the pounding by machine is more thorough, and virtually no human energy is used
- **screw-turn oil press** – this is operated manually to squeeze out the oil from the boiled (steamed) palm fruit and fibre; the pressing technology reduces the time taken for the extraction process and saves fuel for heating in the hot method
- **clarifying tank** – this uses a valve system and heating to reduce the water content of the pressed oil.

Palm kernel oil

Palm kernel, the by-product from the extraction of palm oil, serves as the raw material in the production of palm kernel oil. The traditional method is as follows.

The palm kernel shell is cracked using stones or metal hammers. The freed kernel is put in a container and water is added. The mixture is boiled, with stirring, and then poured into a basket to collect the boiled pebbles of the kernel. The boiling cleans the kernel and makes it easier to grind and extract the oil.

In one method the kernel, collected in a basket, is poured into a basin and a small quantity of kernel oil is poured on it and fried for a short time to induce oil extraction. The oily kernel is then milled in a corn mill. In the past the milling was done tediously on a grinding stone. The ground kernel is mixed with water and boiled thoroughly until sufficient palm kernel oil has collected at the top of the mixture to be skimmed off into a container. The flowchart in Figure 4.61 shows these stages.

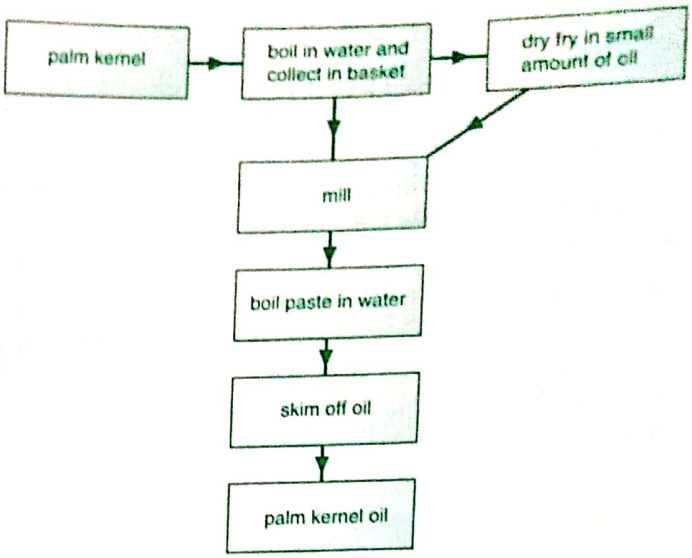


Fig 4.61 Flowchart for palm kernel oil extraction.

In a second method the boiled kernel is not fried but milled directly to follow the same process.

ACTIVITY 6 Visit to a palm oil and palm kernel oil production unit

1 Visit a palm oil and a palm kernel production unit in the locality and report your findings on the following:
   a) the raw material used and its source
   b) the gender strength of workers at the production unit
   c) the distance between the palm oil and palm kernel oil production sites; explain the effects of this finding on the profitability of each of the production enterprises
   d) the sources of energy and water in the production
   e) by-product(s) and waste product(s) in the production process; suggest use(s) for any by-product, and ways to dispose of the waste product
   f) any effects on the environment of the production activities; suggest how any bad effects could be reduced or eliminated altogether.
2 Make suggestion(s) for improved technology in any of the production stages of each oil. Give reasons for the suggestion(s).
3 Draw a flowchart of the production system. Compare it with the flowcharts in Figures 4.63 and 4.64. Explain any difference.
4 Suggest a method of removing the bad odour and the undesirable colour in any of the oils studied.

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Coconut oil

Dry coconuts that have fallen from the tree are picked up, or the matured fruit is harvested.

The coconut fruit is split open through the husk (exocarp) to get to the copra inside. **Copra** is the white pith or the endosperm of the coconut, from which the coconut oil is then extracted.

For any coconut fruit the husk may be removed by hitting the pointed end hard on a stone to loosen it. A cutlass is used to remove the husk and crack open the shell.

The copra is scooped out from its shell with a cutlass or knife. If the copra is difficult to remove, the split fruit is heated lightly in a bread oven to induce separation of the copra from the shell. The free copra is rubbed on a grater to give fine flakes.

Alternatively, the copra is milled into flakes in a corn mill. Water is added to the flakes to form a slurry. The slurry is poured into a clean piece of calico cotton cloth placed over a container. After the liquid has drained through the calico, the sides and ends are held together as a bag, which is wrung to squeeze out as much of the juice as possible. The squeezed water solution of the copra is allowed to stand in the sun until a layer of oil foam collects at the top of the mixture.

The oil foam is skimmed off into an open pan and boiled until coconut oil collects at the top of the mixture. A sludge remains at the bottom of the open pan. It is recycled to make feed for animals.

The resultant mixture is allowed to cool. In the process the clear oil is scooped out with a metal or wooden spoon into suitable containers.

The husk or fibre and the hard shell are the by-products. Both are dried and used as fuel for firing and heating. The hard shell is also heat-charred in the presence of steam to produce activated charcoal and other industrial adsorbents. Adsorbent materials have an active and large surface area capable of attracting and holding small solid and gas particles. Examples of the use of activated charcoal and other adsorbent materials are:

- in gold production, to aggregate (collect) gold particles
- in palm oil, to deodorise (remove colour and/or bad odour)
- in water purification.

The fibre is also used in producing handcrafts such as doormats and brushes, and mosquito coils and repellents. Even waste products, such as copra remnants that are too small for safe hand grating, and the sludge that remains after sun heating the copra juice, are used to produce animal feed (Figure 4.62).

Intermediate technologies have now been introduced at three stages in the production of coconut oil. In general they increase the production rate and quantity

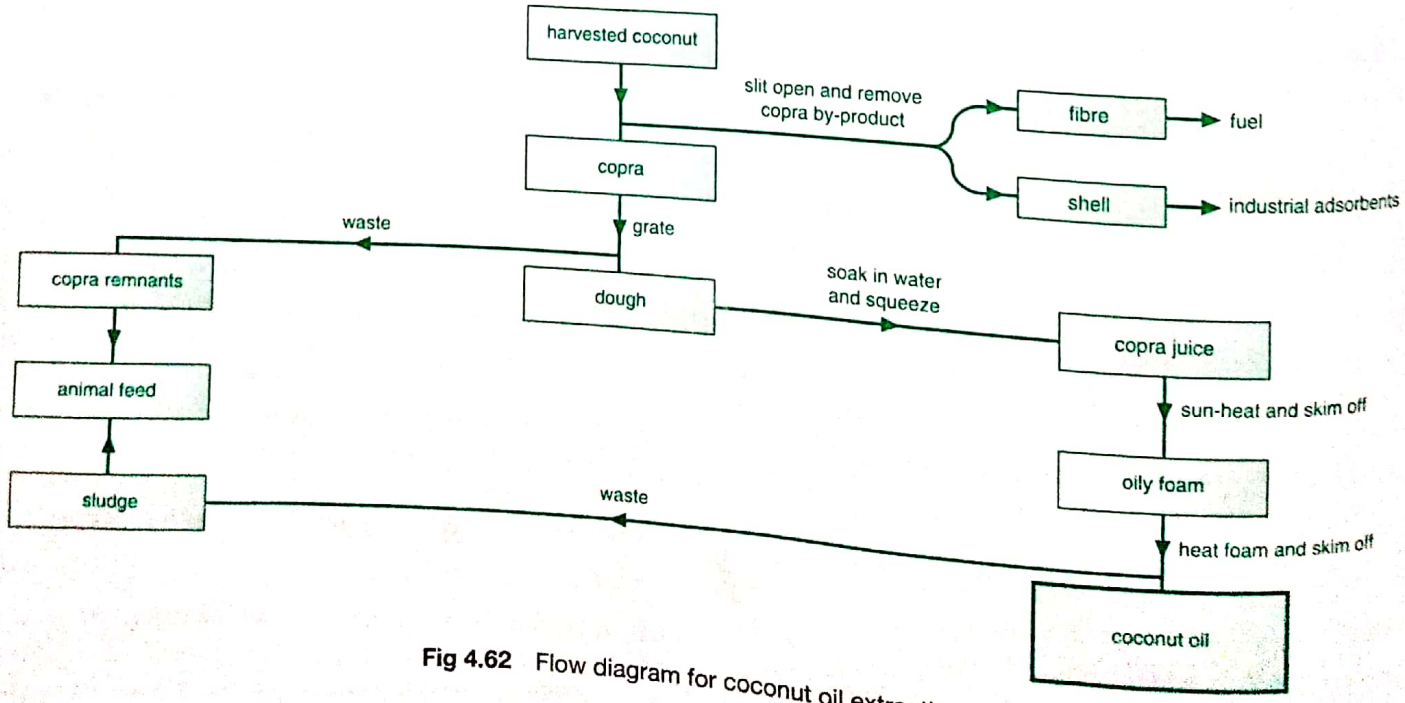


Fig 4.62 Flow diagram for coconut oil extraction.

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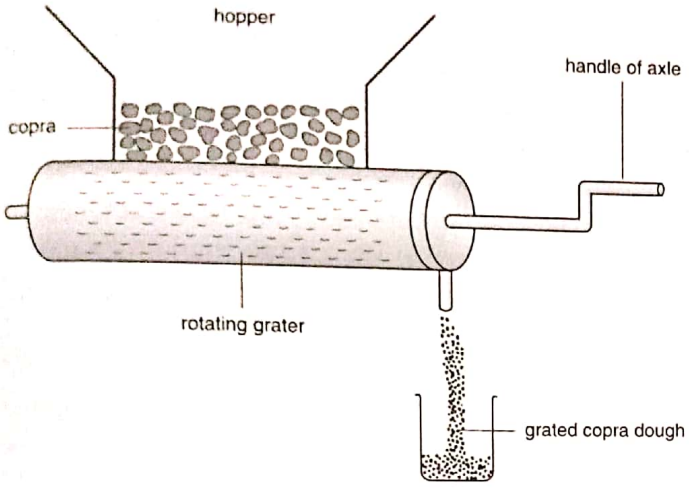


Fig 4.63 Hand-operated copra grater.

of oil by removing manual, tiresome and hazardous operations from the production processes:

- **Hand-operated or machine-operated grater** – a cylindrical grater, turned by hand or by machine, is fed with the copra from a hopper. This increases the rate of production and totally removes the possibility of cuts or other injuries from using a hand grater. The grated copra is discharged into a container (Figure 4.63).
- **Coconut mill** – the copra dough obtained by squeezing the grated copra through calico cloth is milled in a corn mill. The resulting dough has finer-grade particles, and absorbs water more efficiently. It is washed with oily extract from the first wash and water. This additional milling increases oil yield by about 45 per cent.

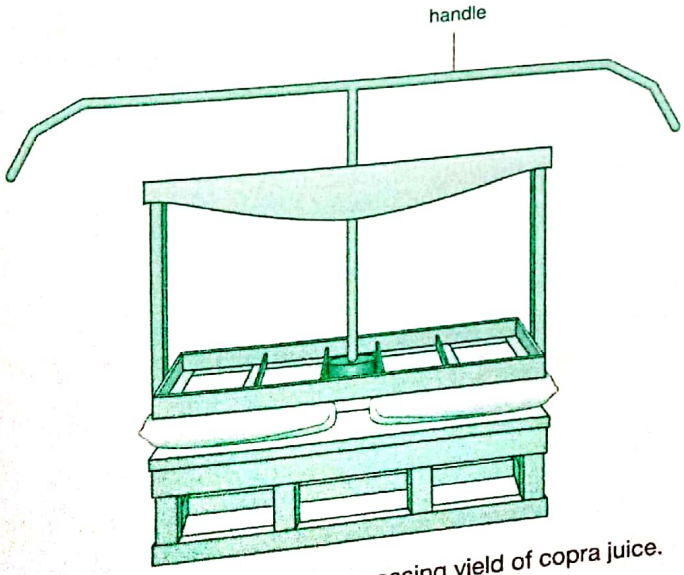


Fig 4.64 Screw press for increasing yield of copra juice.

- **Screw press** – used to exert greater pressure on the milled dough, thus increasing the yield of the copra juice for oil extraction compared with traditional squeezing through calico cloth (Figure 4.64). Large, heavy stones have been used as a press, but they are not as efficient as the screw press.

ACTIVITY 7 Project to study groundnut oil production

1 If you know how groundnut oil is extracted, prepare a brief outline of the extraction processes for discussion. Alternatively, find out from the community how groundnut oil is produced and then write a brief outline of the processes for discussion.

2 Discuss the outline in class as preparation for a visit to a groundnut oil production unit in the community (see Activity 7).

3 Alternatively, a representative from a local groundnut oil production unit could be invited to the school to give a short talk on the essential stages in the production of groundnut oil.

ACTIVITY 8 Visit to a local groundnut oil extraction plant

1 Visit a groundnut oil extraction plant in the community.

2 After the visit, write a report on groundnut oil extraction, to be published in a school magazine or local newspaper. The report should include the following:
   a) the raw material used and its source
   b) gender strength of workers at the plant
   c) distance between the source of raw material and the production site
   d) sources of energy and water in the production
   e) a flowchart of the production system
   f) suggestions for improved technology in any of the production stages, with supporting reasons
   g) by-products and waste products in the production process, with suggested uses for the by-product and ways to dispose of the waste product
   h) environmental effects of production and suggested ways in which they can be minimised or eliminated.

Scientific principles involved in operation of some industries

Salt production

Sea water of high salt concentration is fed or pumped into large ponds. The water is gradually evaporated from the sea water by the sun, aided by wind to form large salt

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crystals. The salt crystals are then cleansed of impurities and crushed into suitable sizes for bagging. Before evaporation, the sea water in the ponds may be mixed with an iodated or iodised salt, which will help protect the final product's consumers from goitre (a thyroid disease). The main scientific processes in the production are evaporation and crystallisation. Salt production is carried out as a medium-scale industry in coastal areas where the sea salt concentration is high, especially in Ada and Accra.

Bread production

Bread production is carried out on various scales in Ghana – small scale in the home to medium scale where some parts of the production processes are carried out by machines. Many of the stages involve simple scientific processes. In a fully mechanised industry, the process is carried out entirely by machines at every stage. The main stages in bread production are as follows:

- **Mixing** – flour is mixed with water and other ingredients such as yeast, baking powder, sugar and salt in a mixing machine.
- **Kneading** – pressing, folding and turning of the product to form a consistent mass; this creates air holes and straightens the gluten (a mixture of proteins) in the flour. Kneading helps the dough in rising; it is done by hand or in a kneading machine.
- **Rising the dough** – kneaded dough is allowed to ferment: the yeast or baking powder produces carbon dioxide gas that increases the size of air bubbles in the dough causing the dough to rise to about double its size. The fermented dough may be punched down flat and kneaded again to break up air holes into smaller ones.
- **Shaping** – the dough is cut into desirable shapes and put into bread pans and allowed to rise again.
- **Baking** – the loaves are put in high temperature ovens to bake. The baked loaves are removed from the pans and allowed to cool ready to be packaged.

Ice cream production

Ice cream can be produced in the home or on various scales industrially. The main steps in the semi-industrial production are outlined:

- **Mixing of raw materials** – milk, cream (fat), sugar, gelatine and flavouring are mixed in a tank. Gelatine acts a stabiliser and gives a smooth consistency in the homogenisation and cooling stages.
- **Homogenisation** – the mixture is processed so that the fat particles break up to form a uniform mixture.
- **Pasteurisation** – the homogenised mixture is heated to a temperature between 55°C and 70°C, or at 70°C for 30 seconds. This destroys harmful bacteria (micro-organisms) but retains the nutrients and flavour of the mixture.
- **Cooling** – the pasteurised mixture is cooled and poured into a freezing container where it is whipped (beaten) to give it a smooth texture. Fruits can be added at this stage. The semi-frozen product is packed into suitable containers and put into refrigerators to harden. On an industrial scale, the **flash freezing** method can be used here, in which liquid nitrogen supercools the ice cream to −195°C to harden well. This method reduces cell spoilage and retains the desired taste when the ice cream is served.

Pomade

Pomade is a moisturising cream or balm made of glycerine and essential oils. It is made by a relatively simple process using beeswax, water and shea butter.

Herbal medicine

Herbal medicine is a growing industry. Traditionally extracted on a small scale, herbs are now extracted and processed on a much larger scale for use both locally and overseas.

ACTIVITY 9 Project to find out about production of pomades and herbal medicines

1 Collect two specimens each of:
   a) pomade
   b) herbal medicine

   with information labels on the containers.
2 Copy out the ingredients that are used in their production.
3 Arrange a visit to a place where either pomade or herbal medicine is produced.
4 Collect any information about the following:
   a) the raw materials used which are obtained locally
   b) the raw materials used which are obtained from outside the country
   c) the number of people employed
   d) the source of energy for the production process

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e) the market for the products
f) a flow chart for the production process, or if not available make one from the description of the process.

5 Write a brief report based on the above and point out the scientific processes involved in the production process.

Self check

For questions 1 to 6, choose the letter that refers to the correct option.

1 In the production of salt in a medium-scale industrial process, which of the following scientific processes are involved?
- **A** cooling and heating
- **B** solar evaporation and crystallisation
- **C** flash processing and evaporation
- **D** saponification and crystallisation

2 Which of following are operated as small-scale industries in Ghana?
- **A** soap and kente production
- **B** aluminium and fish production
- **C** petrol and palm wine production
- **D** fish smoking and aeroplane production

3 Activated charcoal and animal feed are respectively by-products of which of the following industries?
- **A** palm kernel oil and coconut oil production
- **B** kenkey and fufu production
- **C** bread making and salt extraction
- **D** pomade and groundnut oil production

4 The name of the reaction between an alkali and an oil in the preparation of soap is:
- **A** homogenisation
- **B** fermentation
- **C** saponification
- **D** oxidation

5 A nuclear reactor and gold production unit respectively would have which waste problems?
- **A** storage of radioactive reaction products and cyanide poisoning
- **B** plastic litter and cyanide poisoning
- **C** acid rain and faecal odour
- **D** destruction of vegetation and oil spillage

6 Which of these statements about small-scale industry is true?
- **A** it makes use of advanced technology
- **B** it is always capital intensive
- **C** it is always sited in rural areas
- **D** it operates with minimum input of materials

7 In the production of ice cream:
- **a)** explain briefly what the pasteurisation process does
- **b)** state which process is used to:
  - (i) obtain a smooth texture
  - (ii) store the ice cream
- **c)** describe briefly a simple test you would carry out to check the presence or absence of starch in a sample of ice cream.

8 **a)** Write a paragraph describing what the word 'technology' means to you.
b) State two common technological practices that can be found in the community where you live, and describe the skills used in each one.

9 **a)** What are the basic raw materials required for making soap?
b) What substances are mainly responsible for impurities in traditional soap?

10 **a)** State two factors which may be responsible for the low technological development in the community where you live in Ghana.
b) An earthenware cooler and a refrigerator are technological products. Discuss the different sciences involved in the use of the two products.

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3 Biotechnology

Learning objectives

After studying this unit, you should be able to:

1 explain the term biotechnology
2 give examples of industries based on biotechnology
3 explain the meaning of genetic engineering and mention examples of its applications
4 explain the term tissue culture and give examples of its application.

Background information

In Year 3, Section 2, Unit 1 we looked at the effects of harmful microbes. Not all microbes are harmful. Humans have been making use of beneficial microbes for centuries. For example, yeast, a unicellular fungus, has been used for many years for baking and making alcoholic beverages.

Genetic engineers, that is scientists who work with genes, can now 'teach' bacteria to produce chemicals (such as the hormone insulin) that are normally produced only by humans. The 'teaching' process consists of providing one organism with genes from a second organism that is capable of doing something that the first organism cannot do. (See 'Genetic engineering' below.)

Biotechnology and its application

Biotechnology is the industrial and commercial application of biology, particularly of micro-organisms, hormones, enzymology and genetic engineering. It brings together scientists with many different skills – engineers, biologists, chemists and physicists. It is a rapidly growing industry world-wide.

Industries based on biotechnology

Bacteria and fungi in food processing

Many food processing industries in Ghana make use of beneficial bacteria and fungi. Yeast is used in both the fermenting of alcoholic drinks, such as beer, and in bread making. It converts sugar into ethanol and carbon dioxide. Kenkey and Banku are some of the indigenous foods that are prepared from fermented corn dough.

During the fermentation of alcoholic drinks most of the carbon dioxide is allowed to escape into the atmosphere, but the ethanol remains in the fermenting mixture. During baking, the carbon dioxide causes the bread to rise, but the ethanol produced evaporates due to the high temperature of the oven.

Cheese and yoghurt are made by adding certain bacteria to milk.

Industrial fermentation

Micro-organisms like bacteria and yeast produce many substances that are useful to humans, including penicillin, insulin and washing powder enzymes. Because bacteria are so small, to obtain sufficient amounts of the product they have to be grown on a large scale. This is done in an industrial fermenter (Figure 4.65).

The fermenter is a large, stainless steel container which is filled with a suitable growing medium. The micro-organisms are added to the medium and the solution is stirred and aerated. A cooling jacket around the fermenter removes the heat given off by the respiring micro-organisms. When the fermentation is complete, the product is collected via a tap at the bottom of the container. All the equipment must be thoroughly

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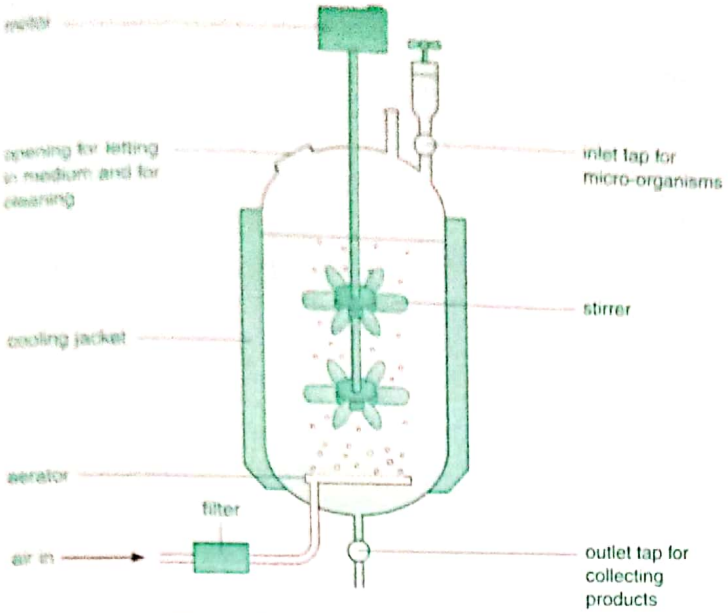


Fig 4.65 An industrial fermenter.

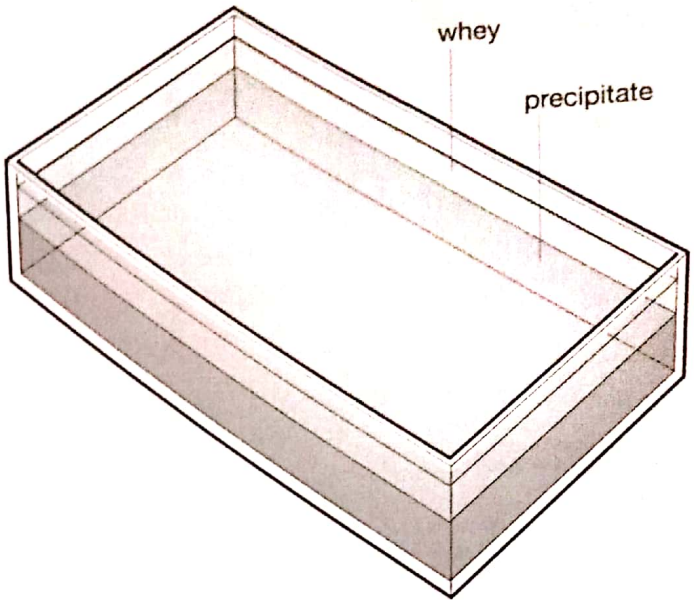


Fig 4.66 Cheese production.

sterilised before use to make sure no unwanted micro-organisms get into the mixture.

Single cell protein (SCP) is made by growing bacteria, fungi or algae in large containers. The cells are then collected and dried and used as high-protein animal feed.

Mycoprotein (food from fungi) is made by growing a fungus on the waste products from flour manufacture. It is high in protein and fibre but contains no cholesterol. It can be given the texture and flavour of meat and can be used as a meat substitute. It is sold under the brand name Quorn™, and is becoming very popular in western countries.

Yoghurt production

Yoghurt is a dairy product produced by bacterial fermentation of milk. Fermentation of the milk sugar (lactose), under controlled temperatures and environmental conditions, produces lactic acid, which acts on milk protein to produce a solid mass (curd) that gives yoghurt its texture and characteristic tang. The increased acidity (pH 4–5) also prevents the proliferation of potentially pathogenic bacteria.

Using *Penicillium* for cheese

Cheese is a milk protein concentrate. Milk protein is known as casein. The milk protein is first precipitated by adding rennet. Rennet is a slimy mucus substance from the stomach wall of a calf, but can also be made synthetically. After precipitation water settles on top of the precipitate. This water is called whey (Figure 4.66). The whey is decanted leaving the precipitated milk protein.

Two species of the fungus *Penicillium* – *Penicillium roqueforti* and *Penicillium camemberti* – are made to grow on the precipitated milk protein, fermenting it in the process to form cheese.

Cheese is a meat substitute and is easily digestible.

ACTIVITY 1 Visiting local industries that use biotechnology

1 Visit a local industry which makes use of microbes in some way. This might be a brewery, bakery or pharmaceutical company, or a research establishment.
2 Make notes about the way in which microbes are being used and what the final product is used for.
3 Write a report of your visit.

ACTIVITY 2 Looking at new products

1 Think of new products that would be useful to your community.
2 Suggest how these could be developed through biotechnology.

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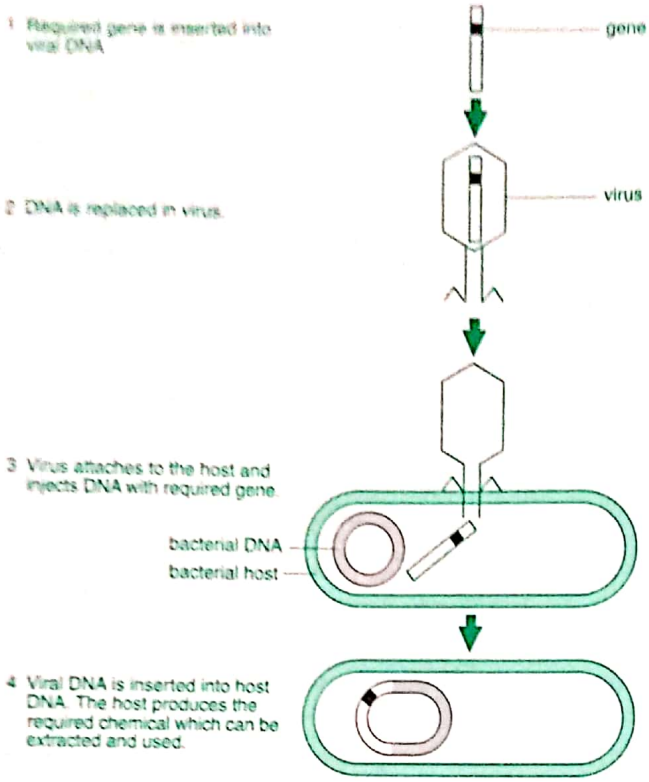


Fig 4.67 Transfer of a useful gene into a host.

Genetic engineering

Humans have been breeding animals and plants to enhance attractive characteristics for many years. This changes the genotype of the organism (Year 3, Section 5, Unit 1). It is now possible to insert a gene from one organism into the genetic material of another organism. This is known as recombinant DNA technology or genetic engineering.

The desired gene is first extracted from the cell and inserted into a vector or carrier. This is often a virus but can be a bacterium. Host cells, for example bacteria, are then infected with the vector and the DNA with the required gene is inserted into the host DNA. The DNA with the inserted gene is called recombinant DNA and is normally a plasmid (ring of DNA) in a bacterium. This DNA is replicated as the bacteria divides. By this process, large quantities of hormones and other useful substances can be produced quickly and easily (Figure 4.67).

Medicine

Stem cell cloning is used in therapeutic research to potentially treat diseases. In medicine in particular, genetic engineering is being used to modify strains

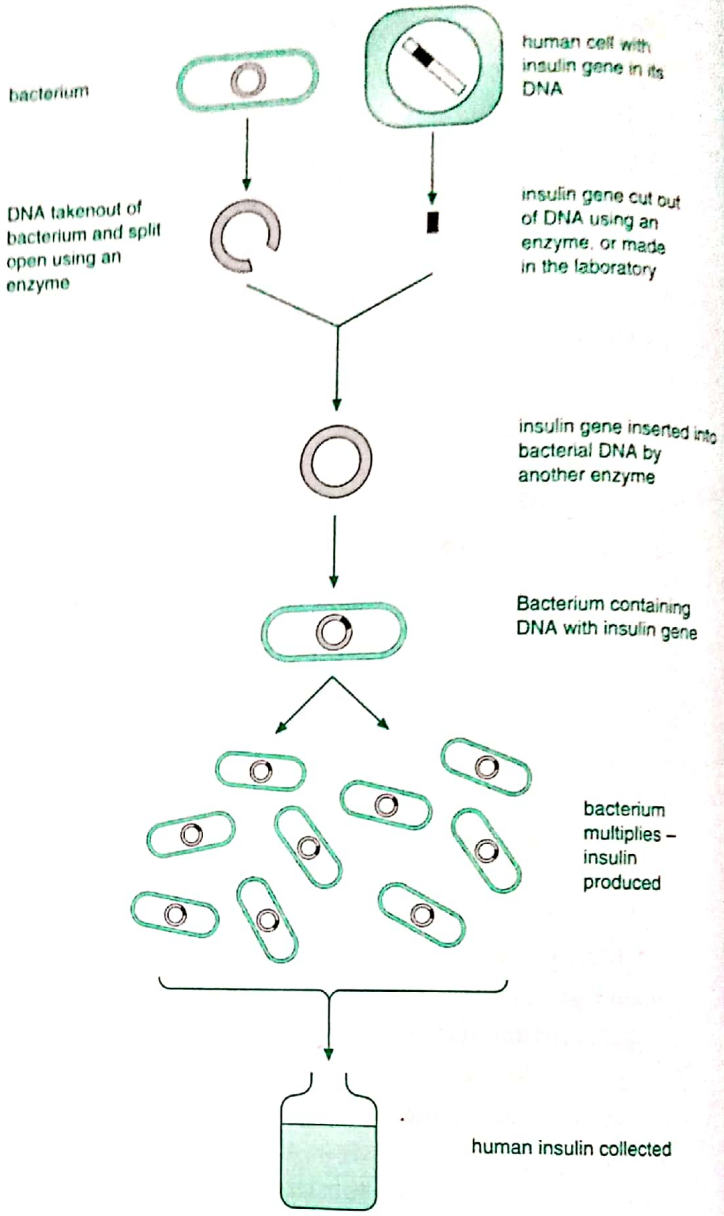


Fig 4.68 Genetic engineering used in insulin production.

of yeast, bacteria, animal and plant cells for the manufacture of hormones that are made up of proteins. Patients whose bodies cannot make these hormones can then be supplied with them. For example, the piece of human chromosome that contains the gene for making the hormone insulin has been identified. The gene is extracted from a human cell using special enzymes. It is then transferred into a bacterium which then makes the insulin (Figure 4.68). Failure of the human body to produce insulin leads to diabetes mellitus. Thus diabetic patients can be given insulin produced by the bacteria.

Biotechnology and genetic engineering have also helped in developing new methods for managing hereditary diseases.

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Pollution

Sometimes, large quantities of oil are accidentally released from tankers into surrounding waters. This causes serious damage to sensitive ecosystems. Genetically engineered bacteria, containing DNA for producing enzymes that break down hydrocarbons and other constituents of oils, have been developed to destroy the oil spills.

Biotechnologists are also working on methods to deal with other types of organic pollutants such as sewage.

Agriculture

Biotechnology and genetic engineering have played a key role in the development of agriculture. Crop plants have been developed that are resistant to herbicides, pesticides and viral diseases. There are now strains of bacteria that can fix nitrogen (change nitrogen to nitrates) in the roots of plants other than legumes. This reduces the need for nitrate fertilisers which are imported in some countries.

Once the function of a particular gene has been identified in a cell, the gene can be changed to give the organism which will develop from the cell a desired characteristic. For example, the following characteristics would be beneficial in cattle bred for meat:

- well-developed, lean muscles
- resistance to disease
- docile and easy to handle.

Maize and millet plants could be developed with the following beneficial characteristics:

- high yielding
- resistant to disease and drought
- short growing season and ability to grow well in different soils
- uniform plant height to assist mechanised harvesting.

Genetically modified foods are foods made from genetically modified organisms (GMOs) that have had their DNA altered through genetic engineering. The most common modified foods are derived from soybean, corn, canola and cotton seed oil.

Tissue culture

Plant tissue culture is a relatively new technique in commercial horticulture. It involves vegetative propagation of shoot tips, tissues and organs of certain plants. Popular plants are pot plants, flowers, vegetable and salad crops.

Very small pieces of tissue are grown in a **culture medium** (a solution of food substances) to give whole new plants of the same kind. Cultures are grown under controlled conditions at 20–25°C (Figure 4.69).

Tissue culture is a method of growing very small amounts of tissue, even one cell, in nutrients to make identical new plants in large numbers.

There are several advantages of propagating plants in this way:

- Large numbers of high-quality plants are produced relatively quickly in a reduced stock plant growing area.

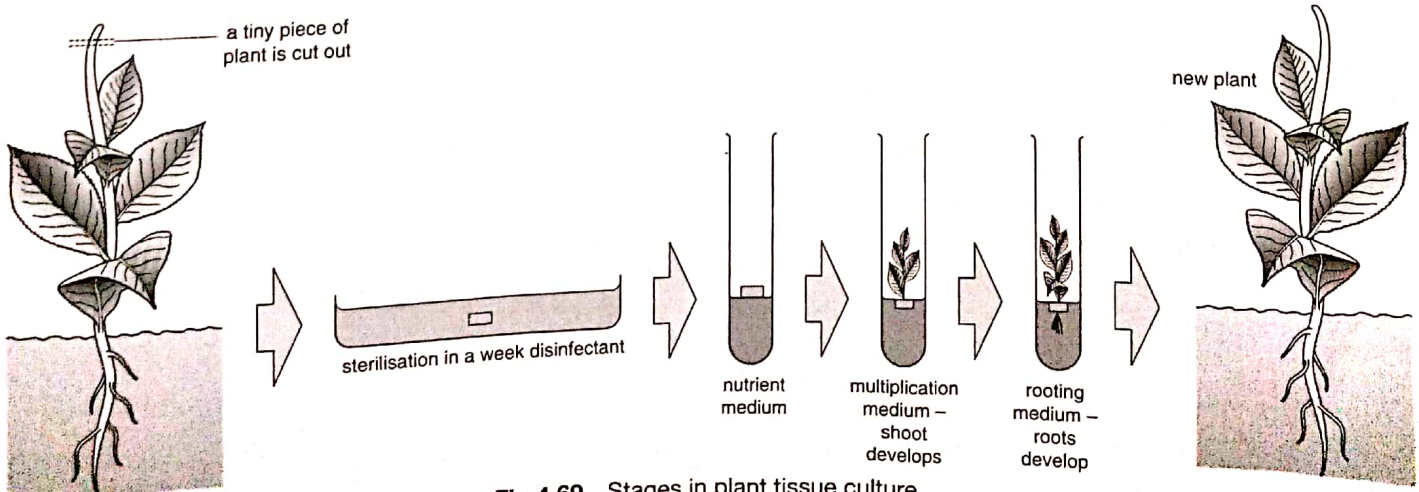


Fig 4.69 Stages in plant tissue culture.

- The propagated new species and varieties of plants are disease free.
- Because the propagation process is highly controlled, the production of plants can be programmed. As in the case of pot-plant production, production can be arranged to meet a regular demand throughout the year.
- The technique encourages plant exports and imports since products are disease free.

ACTIVITY 3 Observing plant tissue culture

1 Visit a tissue culture laboratory.

2 Observe how healthy plants can be produced from small pieces of plant tissue.

ACTIVITY 4 Biotechnology research

1 *Work in groups* to research information about biotechnology using the internet, textbooks or scientific journals.

2 Write a group report on your findings and present to the class.

Self check

For questions 1 to 9, choose the letter that refers to the correct option.

1 Biotechnology involves all of the following people except for:
A biologists **B** engineers
C nuclear scientists **D** chemists

2 Yeast is used in the manufacture of:
A insulin **B** beer
C cheese **D** yoghurt

3 Fermentation of corn dough is brought about by:
A keeping the dough for three or more days
B the action of microbes on the dough
C the presence of water in the dough
D the starch in the dough

4 An industrial fermenter is surrounded by a cooling jacket to:
A freeze the mixture
B insulate the fermenter
C take away the heat produced by the respiring microbes
D absorb the carbon dioxide given off

5 Beneficial characteristics to both maize plants and sheep bred for meat would be:
A resistance to diseases
B development of fatty tissues
C inability to withstand drought
D sensitivity to herbicides

6 The method of growing small amounts of tissue in nutrients to make whole new plants is called:
A plant culture **B** genetic engineering
C tissue culture **D** nutrient culture

7 *Penicillium* is a:
A virus **B** protozoan
C fungus **D** bacterium

8 Which of the following is not a dairy product?
A cheese **B** yoghurt
C butter **D** malt drink

9 Biotechnology is applied in the production of which of the following substances?
I Banku II beer III insulin IV some drugs
A I and II only
B II and III only
C I, II and IV only
D I, II, III and IV

10 **a)** Explain the term 'genetic engineering'.
b) Explain the importance of genetic engineering in the fields of:
(i) medicine
(ii) pollution
(iii) agriculture.

11 **a)** What is tissue culture?
b) Using an appropriate example, briefly describe how it is carried out.

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Revision questions

For the objective questions, select the correct answer from the list labelled A, B, C and D.

1 Weight is measured in
- **A** newtons
- **B** kilograms
- **C** joules
- **D** watts

2 On which of the following laminae is the centre of gravity correctly shown? (see Figure R.1)

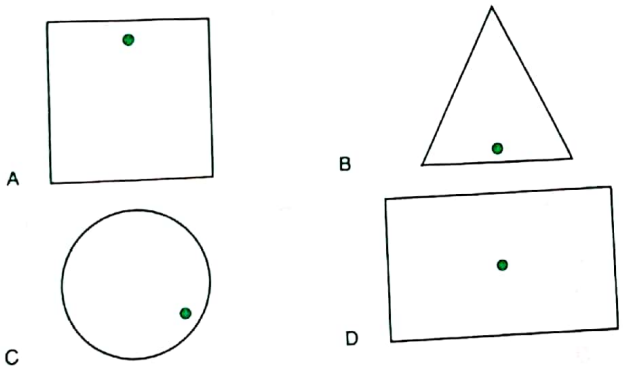


Fig R.1

3 Both organic and inorganic acids have the following properties in common
- **I** they have a strong scent
- **II** they undergo neutralisation reactions
- **III** they produce esters
- **IV** they donate protons

- **A** I only
- **B** II only
- **C** I and II
- **D** II and IV

4 If one parent has a genotype AB and the other has a genotype BO, they cannot produce children with blood group
- **A** AB
- **B** O
- **C** B
- **D** A

5 Which of the following is a bacterial disease?
- **A** tuberculosis
- **B** malaria
- **C** bilharziasis
- **D** measles

6 Which of the following functions does not apply to the skeleton?
- **A** protects soft parts of the body
- **B** produces red blood cells
- **C** supports the body
- **D** contracts to bring about movement

7 The process by which solid iodine changes into a gas is called
- **A** sublimation
- **B** condensation
- **C** evaporation
- **D** freezing

8 Which of the following colours of light is least deviated when white light is passed through a prism? (see Figure R.2)

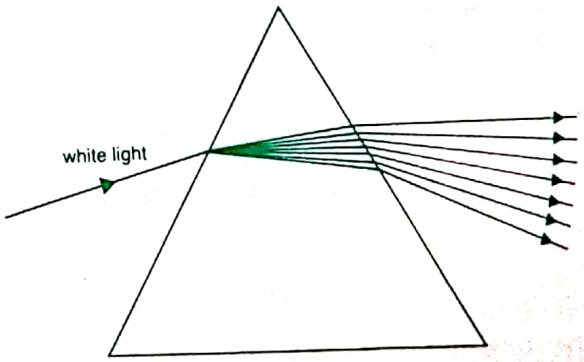


Fig R.2

- **A** blue
- **B** red
- **C** violet
- **D** yellow

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9 An evaporating liquid decreases in temperature because
- A the molecules of the liquid move randomly
- B the liquid is cooled by the surrounding air
- C the escaping molecules take heat energy from the remaining liquid
- D the faster molecules escape from the liquid

10 The work done in lifting a load of 150 N from the floor to a shelf 1.5 m high is
- A 225 J
- B 75 J
- C 750 J
- D 7500 J

11 What is the normal length of a human pregnancy?
- A 28 weeks
- B 32 weeks
- C 40 weeks
- D 52 weeks

12 Which of the following contribute to the formation of rain clouds?
- I transpiration
- II evaporation
- III precipitation

- A I only
- B I and II
- C I and III
- D I, II and III

13 Which of the following mixtures is a colloid?
- A common salt in water
- B sugar in water
- C cooked starch in water
- D alum in water

14 Which of the following can be spread by droplet infection?
- A malaria
- B cholera
- C cancer
- D tuberculosis

15 Which of the following diseases can people not be immunised against?
- A cancer
- B yellow fever
- C polio
- D tuberculosis

16 In the early days before magnetic compasses had been designed, what did seamen use to enable them to navigate across the sea?
- A a solenoid
- B a lump of iron
- C lodestone
- D soft iron

17 Electricity is changed from a very high voltage to the comparatively low voltage used in the home by means of a
- A step-up transformer
- B step-down transformer
- C motor
- D dynamo

18 When standing in deep water in a swimming pool, a person's height appears to be shorter than normal. This is due to
- A refraction
- B reflection
- C total internal reflection
- D dispersion

19 Sulphur dioxide from industrial chimneys forms trioxosulphate(IV) acid (sulphurous acid) during high humidity. This falls as rain, producing
- A acid rain
- B sulphur dioxide rain
- C smog
- D hail and snow

20 Malaria and coccidiosis are both caused by
- A bacteria
- B fungi
- C protozoa
- D viruses

21 Which pollutant is not produced by petrol-driven cars and lorries?
- A sulphur dioxide
- B lead
- C carbon monoxide
- D carbon dioxide

22 Which of the following is an example of a second-class lever?
- A wheelbarrow
- B scissors
- C tongs
- D crowbar

23 In which part of a leaf is the greatest amount of glucose produced during photosynthesis?
- A upper epidermal cells
- B palisade cells
- C spongy mesophyll cells
- D lower epidermal cells

24 A device that moves fluids in one direction only from chamber to chamber is
- A a siphon
- B a hydraulic press
- C an engine
- D a pump

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25 By crossing two heterozygous tall pea plants, the offspring will be
A all dwarf
B all tall
C in the ratio 3 tall: 1 dwarf
D in the ratio 1 tall: 3 dwarf

26 Which part of the body can cataracts affect?
A the heart
B the lungs
C the skin
D the eyes

27 Which of the following combinations is correct for the products of aerobic respiration?
A lactic acid, carbon dioxide, energy, heat
B alcohol, carbon dioxide, energy, heat
C water, carbon dioxide, energy, heat
D carbon dioxide, energy, heat

28 At which position on the principal axis of a converging mirror should an object be placed in order to produce a real, inverted image of the same size as the object itself?
A at the focal point
B between the pole and the focal point
C at the centre of curvature
D at infinity

29 In which of the following media does sound travel fastest?
A water
B air
C iron
D wood

30 Sound can be said to pollute the surroundings when
A the intensity is very high
B the pitch varies a lot
C the sound is produced by striking metals
D the sound is produced by traditional drums

31 The lens of the human eye is dilated or contracted by the action of the
A vitreous humour
B ciliary muscles
C iris
D intensity of light passing through the pupil

32 If a solution is prepared by dissolving 20g of sodium hydroxide (NaOH) to make 1 dm^3 of aqueous solution, what is its concentration in mole per dm^3? (Relative atomic mass of: hydrogen = 1, oxygen = 16, sodium = 23)
A 0.2
B 0.3
C 0.4
D 0.5

33 Some ripe fruits and flowers have a fine smell because
A they have been sprayed with lavender
B they have been washed well
C they contain a mixture of esters (also called alkyl alkanoates)
D they contain certain bases which are also alkalis

34 Hard water can be softened by
I distillation
II neutralising the carbonic acid with lime
III applying ion exchange resin
IV filtration
A I and II
B II and III
C I, II and III
D I, II, III and IV

35 Most external parasites of ruminants can be effectively controlled by
A dipping
B antibiotic treatment
C drenching
D clean feeding

36 Which of the following is a property of enzymes?
A they undergo chemical changes during chemical reactions
B they are decomposed by decomposers
C they work within a wide range of temperatures
D they are found in living organisms

37 Ash from burnt plant materials can be used to prepare local soap because it contains
A ammonia
B hydrochloric acid
C potash
D sodium chloride

38 Which of the following diseases may produce blood in a person's urine?
A measles
B cataracts
C bilharziasis
D rabies

39 Which of the following is likely to be a source of infection for dysentery?
A a mosquito bite
B contaminated food
C improperly cooked meat
D dirty clothes

40 When soft iron is attached to a strong magnet, it becomes
A a permanent magnet
B a temporary magnet
C an electromagnet
D lodestone

41 Soft iron quickly loses its magnetism because it has
A low permeability
B low coercitivity
C high retentivity
D low retentivity

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42 A variable resistor used in stage management to control brightness of lights and as a volume control in radios is called

A a thermostat
B a rheostat
C a thermistor
D a graduator

43 The relative density of the acid in a car battery can be measured with

A a voltmeter
B a potentiometer
C a hygrometer
D a hydrometer

44 If the velocity of sound is 300 m s^{-1}, the wavelength of sound of frequency 120 Hz is

A 0.25 m
B 2.5 m
C 250 m
D 25 m

45 The main advantage of the free range system of keeping poultry is that

A more birds are kept on a unit area of land
B birds can obtain enough green vegetables and grit
C birds interact with others from other poultry houses
D birds provide a high amount of litter for use as manure

46 The pressure, in N cm^{-3}, exerted on the ground by the cube in Figure R.3 is

A 4
B 5
C 10
D 40

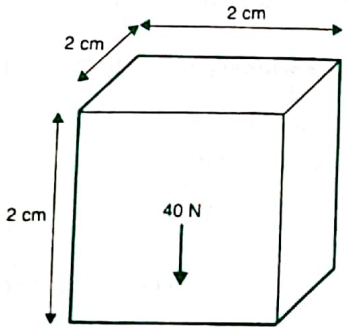


Fig R.3

47 In Figure R.4, the moment of the force, 20 N, about point X is

A 0.25 N cm
B 4 N cm
C 20 N cm
D 100 N cm

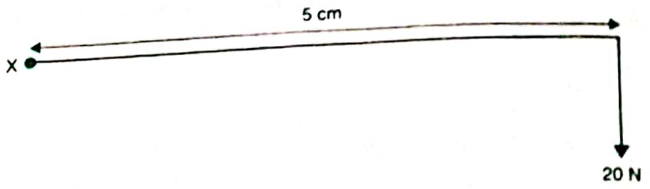


Fig R.4

48 Why is it necessary to format a diskette before use in a computer?

A to enable the diskette to boot the computer
B to make the diskette compatible with the computer
C to provide more working space on the diskette
D to extend the working life of the diskette

49 Pascal's principle states that

A water seeks its own level
B nature abhors a vacuum
C the pressure at any point in a liquid acts equally in all directions
D the pressure in a liquid is proportional to the depth of the point below the surface

50 Sickle-cell anaemia is an example of

A sex-linkage
B multiple alleles
C partial dominance
D blood grouping

51 If 15 children from a class of 45 can roll their tongues, the percentage of rollers is

A 25%
B 40%
C $33\frac{1}{3}$%
D 35%

52 Koplik's spots are a symptom of

A malaria
B typhoid
C measles
D elephantiasis

53 Which of the following is not a name for cannabis?

A hemp
B grass
C pot
D snow

54 Which of the following combinations do all carbohydrates contain?

A sulphur, carbon, hydrogen and oxygen
B carbon, hydrogen and oxygen
C carbon, hydrogen and nitrogen
D carbon, argon and oxygen

55 Which of the following does not contain one-way valves?

A heart
B veins
C capillaries
D lymph vessels

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56 Oxidation is said to occur when a metal joins chemically with
- **A** nitrogen
- **B** oxygen
- **C** another metal
- **D** hydrogen

57 Carbon monoxide is poisonous when inhaled in an enclosed space. How does it poison the body?
- **A** it enters the brain and kills the nerves
- **B** it enters the stomach and causes vomiting
- **C** it blocks the path of oxygen into the blood
- **D** it causes severe headache

58 The energy needed for natural cycles to operate is obtained from
- **A** the air
- **B** the sun
- **C** conservation practices
- **D** decomposers

59 Bronze is an alloy made of
- **A** copper, zinc and tin
- **B** aluminium and copper
- **C** copper and tin
- **D** copper and lead

60 If a child has fever, runny nose, red sore eyes and a rash inside the mouth, which of the following diseases is he likely to be suffering from?
- **A** polio
- **B** malaria
- **C** measles
- **D** whooping cough

61 Which of the following organs does not carry out excretion?
- **A** kidney
- **B** liver
- **C** lung
- **D** brain

62 Which of the following statements is correct about mammals?
- **A** body temperature changes when the surrounding temperature changes
- **B** offspring are hatched from eggs
- **C** body water lost is approximately balanced by body water gain
- **D** hair or fur helps in body water content regulation

63 Using the following organisms, construct a food web: cheetah, grass, antelope, vulture, lizard, locust

64 **a)** List as many ways as you can of measuring growth.
b) What are the advantages and disadvantages of each method?

65 Explain why you can see very little when you first move from a bright light into a fairly dark room. Why can you gradually begin to see the objects in the room?

66 What are the main differences between a clinical thermometer and a laboratory liquid-in-glass thermometer?

67 What advice would you give to a kerosene-seller who often exposes the kerosene to the wind? Explain your answer.

68 **a)** Describe an experiment to show that
(i) soil contains air
(ii) water contains air.
b) What is the importance of air in soil and in water?
c) (i) State the contents of air, showing the approximate percentage of each constituent.
(ii) Explain why air is known to be a mixture, not a compound.
(iii) What are the main functions of the nitrogen in the atmosphere?

69 **a)** Explain how a Thermos flask keeps substances hot or cold.
b) If 3 kg of water (specific heat capacity 4200 J/kg°C) is heated from 16°C to 54°C, how much heat energy would be used in the heating process?
c) State three applications of insulators in the kitchen. What safety precautions would you recommend to a baker baking bread in an oven?

70 Give two examples each of ornamental plants propagated by the following vegetative methods
a) root cuttings
b) leaf cuttings
c) hardwood cuttings.

71 Distinguish between acquired immunity and natural immunity.

72 Give as many reasons as possible to explain why the following can be injurious to a person's health.
a) smoking
b) drinking too much alcohol.

73 State various ways by which running water can be polluted and discuss how polluted water can be purified for human consumption.

74 **a)** State three examples of natural cycles.
b) Describe one of the natural cycles fully, including a diagram in your description.
c) State the importance of this cycle.

75 **a)** Explain each of the following terms:
(i) homeostasis
(ii) warm-blooded
(iii) cold-blooded.
b) Describe the body temperature regulation system in the human body.

76 **a)** What type of organism causes tuberculosis?
b) What are the symptoms of tuberculosis?
c) Describe the precautions that should be taken to prevent the spread of tuberculosis.

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77 a) State the relationship between the mass of a stone and the weight of the same stone.
b) An astronaut has a mass of 74 kg. Calculate his weight (i) on Earth, and (ii) on the moon, if the acceleration due to gravity is 10 m s^{-2} on Earth and 1.6 m s^{-2} on the moon.

78 a) What is meant by the 'emf' of a source?
b) What is meant by the 'pd' across a component in a circuit?
c) What effects are likely to appear when a current flows in a conductor?
d) Explain how one effect of an electric current is used in everyday life.
e) What unit is used to measure an electric current?

79 a) State briefly what you understand by good health.
b) What are the functions of the World Health Organisation?

80 a) What is a lawn?
b) List two ways of maintaining an established lawn.

81 Four resistors have resistances of 20Ω, 60Ω, 100Ω and 50Ω. What is the effective resistance of these four resistors in a circuit if they are connected:
a) in series
b) in parallel
c) as shown in Figure R.5?

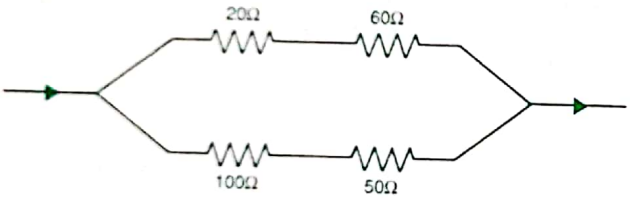


Fig R.5

82 Distinguish between conduction, convection and radiation in the context of heat transfer.

83 State any four characteristics of an image formed in a plane mirror.

84 What is meant by conservation of natural resources? Describe the dangers from abuse of a nation's natural resources.

85 a) List three local sources of fats and oils.
b) Give one large-scale use of each fat or oil listed in (a).
c) State two differences between each of the following pairs:
(i) an organic acid and an inorganic acid
(ii) neutralisation and esterification
(iii) an alkane and an alkene
(iv) an acid and a base.

86 Explain why many electrical appliances are connected to Earth.

87 The centre of gravity of the rod shown in Figure R.6 is at its mid-point. Calculate the force, X newtons, needed to keep the rod in equilibrium.

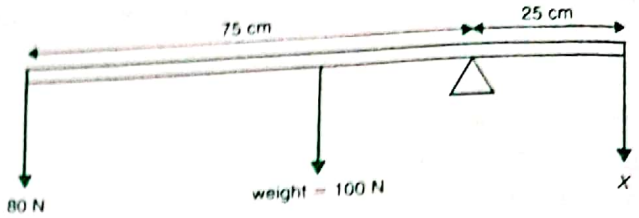


Fig R.6

88 Explain how a leaf can be tested for the presence of starch.

89 Describe the functions of the following structures in the respiratory system:
a) the epiglottis
b) the trachea
c) the alveoli
d) the diaphragm.

90 Describe the difference in composition between inhaled and exhaled air.

91 a) Is the temperature of boiling water in a jug holding 100 m^3 the same as, or different from, the temperature of boiling water in a jug holding 1000 cm^3?
b) If you needed to cool the two amounts of water in (a) to room temperature, which one would take the longer time, or would they take the same time?
c) If you wanted to cool the two amounts of water quickly to room temperature, which one would need the most ice added to it? Explain the difference between the terms 'heat' and 'temperature'.
d) If you were a molecule making up a piece of ice, explain what would happen to you if the ice was heated and went from being ice to being water to being steam?

92 Describe ways in which humans keep cool in hot climates and keep warm in cold climates.

93 Copy the following table of aqueous solutions and give each solution its correct pH from the given list of pH values.

Aqueous solution	pH
rainwater	
orange juice	
0.1 M KOH	
0.1 M NH3	
sodium chloride	
wood ash	

List of pH values: 11, 1, 6, 13, 9, 7.

94 In what ways can the following help in keeping the community healthy?
a) the individual
b) the state.

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95 **a)** State two signs of heat in ruminants.
b) Explain the process of artificial insemination (AI).

96 Explain clearly why it is the father who determines the sex of a baby.

97 Explain the difference between environmental and genetic variation.

98 In an ecological study, a student using a point frame and a quadrat found that 28 points touched a piece of grass. What is the percentage cover of grass in that particular quadrat?

99 Copy the following passages, (a) and (b), and choose the correct words from the list of words given at the end of the question to fill in the blank spaces.

a) The process of ... is used in preparing caustic soda (NaOH) on a large scale. Caustic soda is an example of an .... By-products in the manufacture of caustic soda by this process are ... and hydrogen gas. The first by-product named can be used in manufacturing ... and ....

b) The gas ... is formed in the production of tetraoxosulphate(VI) acid. When some escapes into the atmosphere, it combines with ... to produce ... which can corrode physical structures such as marble because of its ... content. The gas can also pollute ....

List of words to be used: chlorine, plastics, acid rain, sulphur(IV) oxide, trioxocarbonate(IV), rainwater, DDT, rivers, electrolysis, alkali.

100 State how scarcity of water can affect plant and animal life in the area.

101 What factors are likely to contribute to scarcity of drinking water in your District Council area?

102 How are the following diseases spread and how can they be controlled?
a) Guinea worm
b) malaria
c) rabies.

103 **a)** In what forms does solar energy reach the Earth?
b) How is this energy stored?
c) How can it be converted into electricity?
d) What is meant by the word 'power'?
e) How is energy consumed in the home? List appliances which use electricity, what form of energy the electricity is converted into and how each appliance uses that form of energy.

104 **a)** Explain why a fuse is referred to as a safety device in an electric circuit.
b) With which of the three terminals of a plug would you align a fuse? Explain your answer.

105 With the help of a ray diagram, state the characteristics of an image formed by an object placed between the focal point and the pole of a converging mirror.

106 **a)** State four techniques that could help improve crop production in Ghana.
b) Name one organisation which is working specifically on high-yielding crops in Ghana.

107 **a)** Name the six main pollutants that pollute the environment.
b) Suggest ways in which they could be controlled.

108 Write down the formulae for finding the total effective resistance of three resistors if they are wired:
a) in series in a circuit
b) in parallel in a circuit.

109 Name one household appliance that converts electrical energy into each of the following forms:
a) heat energy
b) mechanical energy
c) sound energy.

110 For the cuboid shown in Figure R.7, calculate:
a) its volume
b) its density
c) its weight
d) the maximum pressure that it could exert if placed flat on the ground
e) the minimum pressure that it could exert if placed flat on the ground. (Acceleration due to gravity = 10 m s^{-2}.)

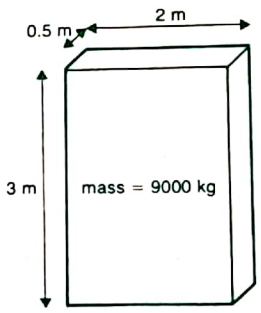


Fig R.7

111 Describe carefully how oxygen in the alveolus gets into a red blood cell.

112 Define the following by reference to human beings:
a) tidal volume
b) vital capacity
c) residual (reserve) volume
d) total lung capacity.

113 **a)** Explain what a drug is.
b) Name five types of drug.
c) Explain why expectant mothers should avoid smoking and excessive drinking of alcohol.
d) Name three dangers of taking drugs other than under the guidance of a medical practitioner.

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114 What are the up-to-date colour codes for the wires of a three-pin plug, listed as follows:

a) live wire
b) neutral wire
c) earth wire?

115 Describe three ways in which the mechanical energy needed for driving a generator in a power station can be provided.

116 A man runs up a flight of stairs in 5 seconds (see Figure R.8). Calculate

a) the man's weight
b) the increase in his potential energy
c) the power generated by him. (Acceleration due to gravity = 10 m s^{-2}.)

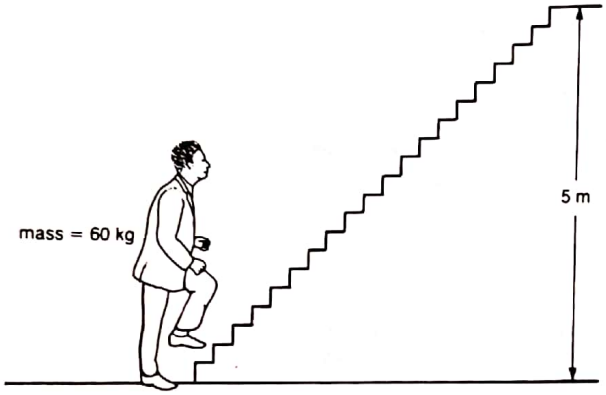


Fig R.8

Answers to self check questions

Year 1

Section 1

Unit 1
1 A; 2 C; 3 D; 4 D

Unit 3
1 A; 2 B; 3 D; 4 B; 5 D

Unit 4
1 C; 2 A; 3 D; 4 D; 5 C; 6 B; 7 B; 8 C; 9 B; 10 A; 11 B; 12 B; 13 C; 14 D; 15 C; 16 A; 17 B; 18 A

Unit 5
1 B; 2 C; 3 A; 4 C; 5 D; 6 C; 7 B

Unit 6
1 B; 2 B; 3 C; 4 A; 5 B; 6 D; 7 A; 8 C; 9 D

Section 2

Unit 1
1 B; 2 D; 3 A; 4 B; 5 C; 6 D; 7 A

Unit 2
1 C; 2 D; 3 B; 4 B; 5 D; 6 D; 7 D; 8 C; 9 A

Section 3

Unit 1
1 C; 2 A; 3 C; 4 A; 5 A; 6 C; 7 A; 8 C

Unit 2
1 C; 2 D; 3 D; 4 D; 5 C; 6 A; 7 A; 8 C; 9 B; 10 D; 11 B; 12 A; 13 C

Unit 3
1 B; 2 A; 3 B; 4 C; 5 D

Unit 4
1 D; 2 C

Unit 5
1 C; 2 B; 3 D; 4 B; 5 A; 6 C

Unit 6
1 B; 2 D; 3 D

Section 4

Unit 3
1 D; 2 B; 3 C; 4 C; 5 A; 6 C; 7 B; 8 A

Section 5

Unit 1
1 A; 2 C; 3 D; 4 B; 5 D; 6 B; 7 C; 8 A

Unit 2
1 C; 2 C; 3 D; 4 D; 5 B; 6 B

Unit 4
1 C; 2 D; 3 C; 4 D; 5 B; 6 A; 7 C; 8 C; 9 B; 10 C

Year 2

Section 1

Unit 1
1 C; 2 D; 3 D; 4 C; 5 C; 6 D; 7 C

Unit 2
1 C; 2 D; 3 B; 4 D; 5 B; 6 C; 7 B; 8 C; 9 B; 10 A

Unit 3
1 C; 2 C; 3 D; 4 D; 5 B

Section 2

Unit 1
1 D; 2 D; 3 C; 4 D; 5 B

Unit 2
1 D; 2 B; 3 A; 4 D; 5 D

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Section 3

Unit 1
1 A; 2 D; 3 C; 4 B; 5 C

Unit 2
1 C; 2 B; 3 B; 4 C; 5 D; 6 C; 7 A; 8 A; 9 C; 10 D; 11 C

Unit 3
1 A; 2 C; 3 A; 4 B; 5 D; 6 A

Section 4

Unit 3
1 D; 2 A & B; 3 A–III, B–I, C–IV, D–II; 4 A–III, B–I, C–II

Section 5

Unit 2
1 A; 2 A; 3 C

Unit 3
1 A; 2 C; 3 B; 4 C; 5 B; 6 B; 7 D; 8 C; 9 D; 10 C; 11 B; 12 A; 13 C; 14 A; 15 C

Year 3

Section 1

Unit 1
1 A; 2 A; 3 B; 4 C; 5 C

Unit 2
1 A; 2 A; 3 D; 4 C; 5 B; 6 B

Unit 3
1 C; 2 D; 3 C; 4 C; 5 B

Section 2

Unit 1
1 C; 2 B; 3 B; 4 B; 5 A; 6 B; 7 C; 8 A

Unit 2
1 B; 2 A; 3 C; 4 B; 5 B; 6 D; 7 C; 8 A; 9 D; 10 C; 11 A; 12 C; 13 D

Section 3

Unit 1
1 C; 2 A; 3 B; 4 A; 5 B

Section 4

Unit 1
1 B; 2 A; 3 C; 4 D; 5 C; 6 B; 7 C; 8 C; 9 B; 10 D; 11 B; 12 C; 13 C; 14 D

Unit 2
1 B; 2 C; 3 A; 4 C; 5 D; 6 C; 7 A; 8 D; 9 B; 10 B; 11 D; 12 A; 13 B; 14 D; 15 A; 16 C; 17 A

Unit 3
1 B; 2 B; 3 C; 4 D; 5 A

Section 5

Unit 1
1 C; 2 B; 3 A; 4 A; 5 D; 6 C; 7 A; 8 B; 9 D; 10 D; 11 B; 12 A

Year 4

Section 1

Unit 1
1 B; 2 B; 3 B; 4 C

Section 2

Unit 1
1 B; 2 A; 3 C; 4 B; 5 B; 6 A; 7 C; 8 A; 9 B; 10 C; 11 D; 12 A; 13 C; 14 B; 15 B; 16 C; 17 A; 18 C; 19 D; 20 B

Section 4

Unit 1
1 D; 2 C; 3 C; 4 A; 5 C; 6 B; 7 B; 8 A

Section 5

Unit 1
1 C; 2 B; 3 D

Unit 2
1 B; 2 A; 3 A; 4 C; 5 A; 6 D

Unit 3
1 C; 2 B; 3 B; 4 C; 5 A; 6 C; 7 C; 8 D; 9 D

Answers to revision questions

1 A; 2 D; 3 D; 4 B; 5 A; 6 D; 7 A; 8 B; 9 C; 10 A; 11 C; 12 B; 13 C; 14 D; 15 A; 16 C; 17 B; 18 A; 19 A; 20 C; 21 A; 22 A; 23 B; 24 D; 25 C; 26 D; 27 C; 28 C; 29 C; 30 A; 31 B; 32 D; 33 C; 34 C; 35 A; 36 D; 37 C; 38 C; 39 B; 40 B; 41 D; 42 B; 43 B; 44 B; 45 B; 46 C; 47 D; 48 B; 49 C; 50 C; 51 C; 52 C; 53 D; 54 B; 55 C; 56 B; 57 C; 58 B; 59 C; 60 C; 61 D; 62 C; 69 b) 478 800 J 77 b) (i) 740 N (ii) 118.4 N 81 a) 230 Ω b) 10.3 Ω c) 52.2 Ω 87 340 N 110 a) 3 m^3 b) 3000 kg m^{-3} c) 90 000 N d) 90 000 N m^{-2} e) 15 000 N m^{-2} 116 a) 600 N b) 3000 J c) 600 W

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Appendices

Appendix I SI units

	Quantity (Symbol)	Unit	Symbol	Definition
Base units	length (l)	metre	m	
	mass (m)	kilogram	kg	
	time (t)	second	s	
	electric current (I)	ampere	A	
	temperature (T)	kelvin	K	
	amount of substance (n)	mole	mol	
	luminous intensity (I_v)	candela	cd	
Derived units	force	newton	N	$kg\ m\ s^{-2}$
	pressure	pascal	Pa	$N\ m^{-2}$
	work, energy, heat	joule	J	$N\ m$
	power	watt	W	$J\ s^{-1}$
	frequency	hertz	Hz	s^{-1}
	electric charge	coulomb	C	$A\ s$
	electric potential (pd) / electromotive force (emf)	volt	V	$J\ C^{-1}$
	electric capacitance	farad	F	$C\ V^{-1}$
	electric resistance	ohm	Ω	$V\ A^{-1}$

Appendix II Size scale

Giant cells, eggs, protoctists like *Amoeba*	Most cells	Cell granules, bacteria	Viruses, many cell organelles, macromolecules	Molecules	Atoms
1 mm	$\frac{1}{10}$ mm – $\frac{1}{500}$ mm	$\frac{1}{500}$ mm – $\frac{1}{10}$ μm	$\frac{1}{10}$ μm – $\frac{1}{500}$ μm	$\frac{1}{100}$ μm – $\frac{1}{5}$ nm	$\frac{1}{5}$ nm – $\frac{1}{1000}$ nm

Approximate limit of unaided vision = $\frac{1}{70}$ mm

Approximate limit of resolution of light microscope = $\frac{1}{10}$ μm

Width of cell membrane = $\frac{1}{100}$ μm

Approximate limit of resolution of electron microscope = $\frac{1}{1000}$ μm

mm = millimetre

μm = micrometre

nm = nanometre

1000 μm = 1 mm

1000 nm = 1 μm

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Appendix III Periodic table of the elements

Group 1	Group 2											Group 3	Group 4	Group 5	Group 6	Group 7	Group 0
																	2 4.0 He Helium
3 6.9 Li Lithium	4 9.0 Be Beryllium											5 10.8 B Boron	6 12.0 C Carbon	7 14.0 N Nitrogen	8 16.0 O Oxygen	9 19.0 F Fluorine	10 20.2 Ne Neon
11 23.0 Na Sodium	12 24.3 Mg Magnesium											13 27.0 Al Aluminium	14 28.4 Si Silicon	15 31.0 P Phosphorus	16 32.1 S Sulphur	17 35.5 Cl Chlorine	18 39.9 Ar Argon
19 39.1 K Potassium	20 40.1 Ca Calcium	21 45.0 Sc Scandium	22 47.9 Ti Titanium	23 50.9 V Vanadium	24 52.0 Cr Chromium	25 54.9 Mn Manganese	26 55.8 Fe Iron	27 58.9 Co Cobalt	28 58.7 Ni Nickel	29 63.5 Cu Copper	30 65.4 Zn Zinc	31 69.7 Ga Gallium	32 72.6 Ge Germanium	33 74.9 As Arsenic	34 79.0 Se Selenium	35 79.9 Br Bromine	36 83.8 Kr Krypton
37 85.5 Rb Rubidium	38 87.6 Sr Strontium	39 88.9 Y Yttrium	40 91.2 Zr Zirconium	41 92.9 Nb Niobium	42 95.9 Mo Molybdenum	43 99 Tc Technetium	44 101 Ru Ruthenium	45 103 Rh Rhodium	46 106 Pd Palladium	47 108 Ag Silver	48 112 Cd Cadmium	49 115 In Indium	50 119 Sn Tin	51 122 Sb Antimony	52 128 Te Tellurium	53 127 I Iodine	54 131 Xe Xenon
55 133 Cs Caesium	56 137 Ba Barium	57 – 71 Lanthanide series	72 178 Hf Hafnium	73 178 Ta Tantalum	74 184 W Tungsten	75 186 Re Rhenium	76 190 Os Osmium	77 192 Ir Iridium	78 195 Pt Platinum	79 197 Au Gold	80 201 Hg Mercury	81 203 Tl Thallium	82 207 Pb Lead	83 209 Bi Bismuth	84 210 Po Polonium	85 210 At Astatine	86 222 Rn Radon
87 223 Fr Francium	88 226 Ra Radium	89 – 103 Actinide series	104 260 Rf Rutherfordium														

1 1.0 H Hydrogen

boundary between metals (to the left) and non-metals (to the right)

Transition elements

Atomic number on the left

Relative atomic mass on the right

Lanthanide series	57 139 La Lanthanum	58 140 Ce Cerium	59 141 Pr Praseodymium	60 144 Nd Neodymium	61 147 Pm Promethium	62 150 Sm Samarium	63 152 Eu Europium	64 157 Gd Gadolinium	65 159 Tb Terbium	66 162.5 Dy Dysprosium	67 165 Ho Holmium	68 167 Er Erbium	69 169 Tm Thulium	70 173 Yb Ytterbium	71 175 Lu Lutetium
Actinide series	89 227 Ac Actinium	90 232 Th Thorium	91 231 Pa Protactinium	92 238 U Uranium	93 237 Np Neptunium	94 242 Pu Plutonium	95 243 Am Americium	96 247 Cm Curium	97 247 Bk Berkelium	98 251 Cf Californium	99 254 Es Einsteinium	100 253 Fm Fermium	101 256 Md Mendelevium	102 254 No Nobelium	103 257 Lr Lawrencium

semi-metals

Appendix VI Common sources of food classes

Name of food	Protein g	Fat g	Carbohydrate g	Calcium mg	Iron mg	Vitamin A mg	Thiamine mg	Riboflavin mg	Nicotinic acid mg	Ascorbic acid mg	Water g	Kilojoules
Carrot	1	0.3	10	42	0.7	3.0	0.07	0.06	0.6	10	87	202
Cassava (fresh root)	0.07	0	35	25	0.5	0	0.02	0.07	0.6	30	62	605
Cassava (dried root)	2	0	80	55	1.0	0	0.05	0.07	1.2	0	12	1 378
Irish potato	2	0	19	11	0.7	0.01	0.10	0.05	1.0	15	77	353
Sweet potato	1.8	0.7	27	30	0.7	1.5	0.10	0.06	0.7	16	68	508
Yam	2	0	25	15	1.0	–	0.05	0.06	0.4	15	70	454
Cow pea	24	1	44	90	4	–	0.89	0.14	1.3	–	10	1 180
Ground nut	26	46	10	50	2	–	0.75	0.15	17.4	–	6	2 344
Kidney bean	24	2	48	120	8	–	0.45	0.34	2.3	–	10	1 285
Soyabean	35	18	12	250	7	–	1.0	0.31	2.1	–	7	1 470
Beans and peas (fresh with pod)	2	0.2	6	65	2.0	0.18	0.08	0.01	0.6	15	90	139
Green peppers	1.5	0.2	6	15	0.5	0.22	0.05	0.04	0.4	150	88	134
Plantain, bananas	1	–	14	30	0.5	0.03	0.05	0.06	0.5	10	80	260
Pumpkin, marrow, etc.	1.2	0.1	7	20	0.8	0.9	0.05	0.08	0.6	10	90	147
Tomatoes	1	–	4	15	0.4	0.3	0.05	0.04	0.7	25	92	88
Amaranthus and similar leaves	4	–	5	200	3.5	2.7	0.15	0.17	0.7	70	88	168
Cabbage and similar leaves	1.5	–	3	40	0.5	0.15	0.10	0.06	0.3	30	93	84
Sweet potato and similar leaves	2.3	–	4	200	3.0	2.1	0.09	0.17	0.3	100	90	118
Banana (sweet)	1.2	–	23	8	0.6	0.12	0.09	0.06	0.6	10	75	420
Lemon and limes	0.5	–	9	14	0.1	0	0.03	0.02	0.15	35	90	168
Mango	0.7	–	12	20	0.5	0.18	0.06	0.05	0.2	20	83	214
Oranges	0.8	–	10	30	0.5	0.06	0.08	0.03	0.2	45	86	185
Pawpaw	0.6	–	9	10	0.5	0.75	0.02	0.02	0.1	80	89	160
Cashew nuts	20	45	21	50	5	–	–	–	–	–	5	2 398
Coconut kernel	4	38	12	24	2	–	0.11	–	0.4	–	43	1 697
Dates (dried)	2	–	69	70	2	0.03	0.07	0.04	2.2	0	20	1 193
Sesame seed	20	50	10	1 500	15	–	0.42	–	–	–	5	2 394
Sugar (brown)	0.2	0	96	30	2	–	0.02	0.1	0.3	–	3	1 634
Sunflower seed (kernel)	27	45	14	100	7	–	–	–	–	–	6	2 390
Maize (whole grain)	10	4.5	70	20	4	0.03	0.45	0.14	1.5	–	11	1 461
Maize meal	9.5	4.0	68	18	3	0.03	0.35	0.10	1.0	–	12	1 462
Millet	8	1.3	72	35	5	–	0.30	0.05	1.4	–	12	1 394
Rice (pounded)	8	2.0	76	15	2	–	0.24	0.10	2.0	–	12	1 487
Rice (polished)	7	1.0	78	5	0.5	–	0.05	0.05	1.0	–	12	1 466
Sorghum	10	3.0	70	25	5	–	0.50	0.12	3.5	–	12	1 457
Wheat flour (brown)	11	1.6	70	30	4	–	0.30	0.10	2.0	–	13	1 420
Wheat bread (brown)	8	1.1	49	20	3	–	0.21	0.07	1.4	–	40	1 000
Beef (lean)	22	8	–	12	3	0	0.10	0.15	5.0	–	66	672
Chicken	19	7	–	15	2	0	0.15	0.15	6.0	–	73	584
Liver	18	5	–	10	12	6.0	0.30	2.5	16.0	–	71	491
Mutton (sheep or goat)	18	9	–	10	2.7	0	0.20	0.27	5.0	–	72	643
Pork (lean)	14	35	–	8	1.8	0	0.80	0.18	3.0	–	50	1 558
Snails	12	1.4	4	150	8	–	–	0.5	1.3	–	78	336
Freshwater fish	18	2.5	0	50	1	–	0.03	0.05	1.5	–	79	339
Salt dried fish	42	4.0	0	180	2	0.01	0.06	0.24	5.0	–	35	857
Sea fish	19	1.0	0	20	1	–	0.07	0.07	4.2	–	77	340
Butter	0.6	82	0.4	16	–	0.9	0	0.01	0.1	0	15	3 108
Eggs (chicken's)	13	11	–	54	2.8	0.3	0.01	0.03	0.1	–	75	634
Ghee	0	98	0	0	–	0.9	0	0.01	0	0	1	3 704
Milk (cow or goat)	4	4	4.6	130	–	0.04	0.05	0.13	0.1	1	87	294
Milk (human)	1.4	3.7	7.2	30	–	0.02	0.03	0.06	0.1	1	88	286

Amounts per 100 g edible portion

0 = none present
– = not known

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Appendix IV WAEC adapted IUPAC nomenclature for some inorganic substances

Binary compounds

Formula	Common name	WAEC adapted IUPAC name
CO_2	carbon dioxide	carbon(IV) oxide or carbon dioxide
CO	carbon monoxide	carbon(II) oxide or carbon monoxide
SO_2	sulphur dioxide	sulphur(IV) oxide or sulphur dioxide
SO_3	sulphur trioxide	sulphur(VI) oxide or sulphur trioxide
NO_2	nitrogen dioxide	nitrogen(IV) oxide or nitrogen dioxide
PbO	lead monoxide	lead(II) oxide
PbO_2	lead dioxide	lead(IV) oxide
FeO	ferrous oxide	iron(II) oxide
Fe_2O_3	ferric oxide	iron(III) oxide
HCl	hydrogen chloride	hydrogen chloride
H_2O	water	water
NH_3	ammonia	ammonia
K_2O	potassium oxide	potassium oxide
K_2O_2	potassium peroxide	potassium peroxide
KO_2	potassium superoxide	potassium superoxide
PCl_3	phosphorus trichloride	phosphorus(III) chloride
PCl_5	phosphorus pentachloride	phosphorus(V) chloride

Oxoanions

Formula	Common name	WAEC adapted IUPAC name
SO_4^{2-}	sulphate ion	tetraoxosulphate(VI) ion
SO_3^{2-}	sulphite ion	trioxosulphate(IV) ion
NO_3^-	nitrate ion	trioxonitrate(V) ion
NO_2^-	nitrite ion	dioxonitrate(III) ion
CO_3^{2-}	carbonate ion	trioxocarbonate(IV) ion
HCO_3^-	hydrogen carbonate ion	hydrogentrioxocarbonate(IV) ion
ClO^-	hypochlorite ion	oxochlorate(I) ion
ClO_4^-	perchlorate ion	tetraoxochlorate(VII) ion
MnO_4^-	permanganate ion	tetraoxomanganate(VII) ion

Acids

Formula	Common name	WAEC adapted IUPAC name
H_2SO_4	sulphuric acid	tetraoxosulphate(VI) acid
H_2SO_3	sulphurous acid	trioxosulphate(IV) acid
H_2CO_3	carbonic acid	trioxocarbonate(IV) acid
HNO_3	nitric acid	trioxonitrate(V) acid
HNO_2	nitrous acid	dioxonitrate(III) acid
HCl(aq)	hydrochloric acid	hydrochloric acid

Bases

Formula	Common name	WAEC adapted IUPAC name
NaOH	sodium hydroxide	sodium hydroxide
$Fe(OH)_2$	ferrous hydroxide	iron(II) hydroxide
$Fe(OH)_3$	ferric hydroxide	iron(III) hydroxide
$NH_4(OH)$	ammonium hydroxide	aqueous ammonia/ammonia solution

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Salts

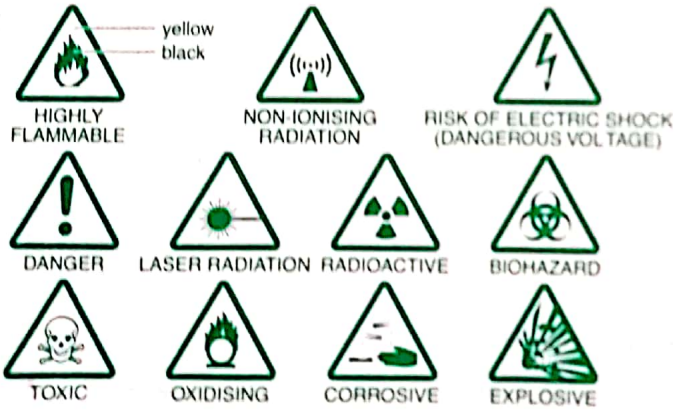
Formula	Common name	WAEC adapted IUPAC name
Na_2SO_4	sodium sulphate	sodium tetraoxosulphate(vi)
Na_2CO_3	sodium carbonate	sodium trioxocarbonate(iv)
$NaNO_3$	sodium nitrate	sodium trioxonitrate(v)
$CuSO_4$	cupric sulphate	copper(v) tetraoxosulphate(vi)
NaCl	sodium chloride	sodium chloride
hydrated salts		
$Na_2CO_3.10H_2O$	hydrated sodium carbonate (washing soda)	sodium trioxocarbonate(iv) decahydrate
$FeSO_4.7H_2O$	ferrous sulphate heptahydrate	iron(ii) tetraoxosulphate(vi) heptahydrate
$Fe_2O_3.nH_2O$	hydrated iron oxide (rust)	iron(iii) oxide xhydrate
$Al_2O_3.nH_2O$	hydrated aluminium (bauxite)	aluminium(iii) oxide xhydrate

Appendix V Hazard/safety symbols

Safety signs may be fixed to doors, cupboards, etc., to give information to those in the vicinity. They are subject to regulations which differ from those requiring hazard warning symbols on bottles or equipment, although in some cases the same basic symbol may be used.

Warning signs

These warn of a hazard. They are enclosed in a triangle and are black on a yellow background. Examples include:



Containers of hazardous chemicals

These must normally bear a hazard warning symbol (and certain approved risk phrases). In this case the symbol is contained within a square (or in a diamond shape in the case of vehicles). Examples include:



Mandatory signs

These indicate that a specific course of action must be taken. Examples include:



Prohibition signs

These indicate behaviour that is prohibited (e.g. no naked flames, do not extinguish with water). Examples include:



Safe condition signs

These provide information on safe conditions. For example:



Index

abiotic factors 151–3
abortion 250, 251, 252, 253
absorption of food
  in humans 117, 120
  in plants 128–9
AC (alternating current) 148, 270
acceleration 10, 17, 133, 301, 305, 306–7
accidents 7, 314–15, 383
acetic acid 447–8
acetylene 445
acid-base indicators 196–8
acid rain 65, 169
acidity, soil 204, 208
acids
  alkanoic acids 447–8
  definition of 188
  indicators 196–9
  with metals 190
  neutralisation 191–2
  properties 189–92, 199
  safety 189
  sources of 186–7
  uses 192, 193
activated charcoal 341, 510
active transport 128
adaptations 150, 152, 155
  in plants 79–80
addition reactions 444–5
adolescence 256
adrenal glands 387
adrenaline 388
adulthood 257
aeration 220
aerobic respiration 9495
aeroplanes 303–4
afterbirth 247, 248
age 256–7
agriculture *see also* crops; farm animals
  agricultural waste 230
  agrochemicals 153, 166
  biotechnology 517
  ecology and 139
  efficiency 328
  genetic engineering 517
  radiation 489
  recycling 329
  soil and 58, 201, 207–8
  solar energy 139
  technology and 504
  waste water 231, 328
agro-forestry 201
agro-industries 367
AIDS 179, 243, 253, 254
air *see also* atmosphere
  pollution 65, 166
  pressure in 310–11
  properties 404
  reactions 337–8
air-borne diseases 178–9
air masses 63–4, 65
air resistance 302, 304
albinism 428
alcoholic drinks 121, 383
algae 26, 28
alimentary canal 115–19
alkalis 187
  Bronsted-Lowry definition 188–9
  neutralisation 191–2
  non-metals 338
  soap making 506–8
  uses of 506–7
alkanes 442, 444
alkanoic acids 447–8
alkanols 446–8
alkenes 442, 444
alkyl alkanoates 448–50
alkynes 444
alleles 426, 429, 431
allotropy 341
alloys 341–2, 353
alpha particles 487, 488
alternating current (AC) 148, 270
altitude 153, 424
aluminium
  extraction 344–6
  oxidation 350
  properties 337, 404, 413
  reactions 338
  reactivity 353
  uses 339
alveoli 97, 99
amino acids 121
  deamination 121, 235
  decomposition 68
  in digestion 117, 119, 120
  gene mutation 425
  proteins and 105
  in silage 465–6
  in transport 129
ammeters 296
ammonia 187, 188–9
  test for 189–90, 191
ammonium chloride 35
ammonium ions 67, 68
ammonium salts 189–90, 191
amniotic fluid 246
amoebic dysentery 360–1
amphoteric metals 337
amplifier circuits 279–81, 492–5
amylase 115, 117
anaemia 266
anaerobic respiration 94–5
androecium 77
androgens 241, 248
animal cells
  osmosis and 126–7
  plant cells and 51–4
  structure and function 49–51
animal feed 366
animals *see also* farm animals
  classification 25, 27, 28–9
  diseases 179–80
  ecosystem relationships 161–3
  nitrogen cycle 68
  tissues 53–4
  water cycle 226
anions 33, 35
annual crops 366
anthrax 467
antibiotics 6, 176, 515
antibodies 265
antigens 429
antitoxins 265
anus 117–18

CamScanner

appendicular skeleton 70, 73
appliances 313–14
applied science 4
aquatic ecosystems 153–6, 169
aqueous solutions 43
aquifers 226
arable crops 366
arboreal animals 157
Archimedes 6–7
Archimedes' principle 303–4
area 11–12
argon 341
Aristotle 20
arteries 109–10, 121, 235, 262–4
arterioles 262
artesian wells 228
arthritis 74
arthropods 23, 27
artificial ecosystems 158
artificial insemination (AI) 456
asexual reproduction 20, 88–91
asthma 100
astigmatism 397
atmosphere
  acid rain 65, 169
  air movement 62
  climate change 164–8
  human activities and 165–6
  ozone layer 168–9
  pollution 166
  speed of sound 284–5
atomic bombs 490
atomic mass 41, 488
atomic mass unit 41
atomic number 24, 40
atomicity 32
atoms 31, 32–5
autotrophic organisms 103
Avogadro's constant 42
axial skeleton 70, 71–3

babies 255
backyard farming 454
bacteria
  digestive system 117
  fermentation 96, 514–15
  in food processing 514–15
  nitrogen cycle 68
  water treatment 220
bacterial diseases 176–7, 180–1
balance 288
basalt 59
bases
  with ammonium salts 191
  definition of 188–9
  indicators 196–9
  neutralisation 191–2
  properties 35, 189–92, 199
  safety 189
  sources of 187–8
  uses 192, 193
battery cage system 474
bauxite 344
Becquerel, Henri 6
beef cattle 459, 460
benzene 442–5
berries 83
beta particles 487
bicycle pumps 310–11
biennial crops 366
bile 116, 121
Bilharzia 362–3
bimetallic strips 410–11
binary compounds 34–5
binomial system 23–4
biogas 133
biological weapons 165–6
biology 4, 21–4, 25–9
biomes 150
biosphere 150
biotechnology 514–18
biotic factors 153
birds 119
  poultry 469–77
birth 247–8
birth control 258–9
bitumen 453
bladder 235, 236, 238–9
bleach 338
bleeding 315–16
bloat 465, 468
blood
  disorders 266–7
  flow 109–10, 262
  functions of 264–6
  glucose levels 122
  transfusions 430
blood cells
  see red blood cells; white blood cells
blood groups 429–31
blood pressure 110, 266, 317
blood vessels 262–4
  cholesterol 109–10
  hepatic arteries 121
  impotence 253
  lungs 97–8, 100–1
  placenta 78, 245–6
  renal arteries 235
body temperature 14, 122
boiling points 213–14, 215, 414–15
bonds 35–8, 413
  change of state 413, 415
  functional groups 443–4
  multiple 440–1
  representations of 442–3
bones
  see skeletons
boreholes 228
Bowman's capsule 235–6
brain 381–3
  damage to 383
  strokes 110, 266
  voluntary/involuntary actions 384–6
braking force 497
brass 342
bread production 512
breast feeding 249
breathing 98–9
breeding systems 455–6
breezes, land and sea 62–3
bronchi 97
bronchioles 97
bronchitis 101
Bronsted-Lowry definition 188–9, 197
bronze 342
brucellosis 467
bryophytes 26
budding 90
bulbs 88–9
burns 316
bush fires 322–3
butane 442, 443, 445

calcium
  in diet 109, 115
  in hard water 191, 216–17
  reactions 338
  reactivity 353
calcium hydroxide 35, 187, 192, 193, 199, 218
calories 403
calorimeter 404
calves 460–1
calyx 77
cancer 101, 166, 168, 242, 266, 325, 400, 488
canine teeth 112
capacitance 280
capacitors 146, 147, 148, 280–1
capillaries 262–4
carbohydrates 103–5, 109, 119
carbon *see also* organic compounds
  allotropes 341
  properties 440
  reactions 337–8
carbon-12 scale 41
carbon cycle 167
carbon dating 489
carbon dioxide
  in air 45, 165
  combustion 445
  diffusion 124–5
  fermentation 96, 512, 514
  fire extinguishers 315, 322, 326
  in fizzy drinks 192
  greenhouse effect 166–8
  in photosynthesis 103, 140, 142, 143, 239
  in plants 101–2

CamScanner

cudding 458
Curie, M and P 6
current 148, 270
  electromagnetic induction 295–6
  measurement 296
  transformers 274–5
cuttage 372
cuttings 372
cyclones 64
cytoplasm 49

dairy cattle 459–60
Darlington pair 492–5
Darwin, Charles 433
DC (direct current) 270
deamination 121, 235
death 67
decibels 287
decimal multiples 10
decomposition 68, 151
deep litter system 473
deforestation 166, 208, 231
denitrification 68
density 10, 15–17
dentine 111
dentition 112–13
depression 383
desertification 168, 208
deserts 158
detergents 192, 451
detoxification 121–2
development in humans 253–7
diabetes mellitus 110
diamonds 341
diaphragm 98
diatomic molecules 32
diesel 445, 453
diet
  balanced/unbalanced 109–10
  diseases 178
  food substances 103–8
  in pregnancy 250
  variation 424
diffraction 285
diffusion 124–5
  digested food 120, 125
  in the ileum 117
  osmosis and 128
  placenta 246
  in plants 101–2, 125, 128
  respiration 125
  simple organisms 234, 261
digestive system
  diseases and disorders 120–1
  mammals 115–19
  ruminants/non-ruminants 118–19
dilution 46–7
diodes 145
dioxins 325
direct current (DC) 270
disaccharides 104
diseases 176–8
  animals 466, 467–8, 476–7, 481, 484–5
  bacterial 176–7, 180–1
  blood cells and 264
  crops 374–5
  diet and 178
  digestive system 120–1
  and economics 123
  health maintenance 313
  immunisation 249–50
  from pests and parasites 359–65
  public health 327–32
  respiratory system 178–9
  sexually transmitted 238, 253–4
  transmission and symptoms 178–83
  viral 177, 182–3
  water-related 179, 220, 230
  worms 361–3, 364, 467
dispersal, seed 85–6
dispersion of light 397–8
displacement 304–5
distance 304
distillation 133, 218, 445, 452
distilled water 218
diverging lenses 394–5
DNA 422–3, 426, 516
dodder 357
Dolly the sheep 55
dominant alleles 426, 428, 431
Doppler effect 288
dormancy 87
double bonds 37
droughts 168
drug abuse 313, 327, 383
drug dependence 383
drug effects 121–2
drug treatments
  animals 180
  bacterial diseases 180–1
  hazardous 313
  herbal medicine 366
  poultry 476
  sexually transmitted diseases 254
  viral diseases 182–3
  worms 364
dry season 151, 152, 373, 464
duodenum 116
duralumin 342
dust 319–20

early childhood 255–6
ears 288–9
Earth
  land formations 175
  layers of 171–2
  as a magnet 298–9
  plate tectonics 172–5
  temperature 62–3
earth tremors 173
earthquakes 173–4
echinoderms 27
echo sounders 286
echoes 286
ecology 150–3
ecosphere 150
ecosystems 151
  interrelationships 161–3
  types of 153–61
ectopic pregnancy 251
edible oils 508–11
education 505
efficiency 498–9
efficiency of energy 135
effort 498
egestion 117–18
ejaculation 244
elastic potential energy 498
electric power generation 273–4
  magnetism 295–6
  tidal energy 223–4
electric shocks 314, 316, 324
electricity
  circuits 144–9, 270–3, 279–81, 492–5
  electrical power 273
  household wiring 275–6
  measurement 10, 17
  sources of 269–70
  transformation and transmission 274–5
electricity meters 277
electro-magnetic induction 295–6
electrolysis 344–5, 346
electromagnetic spectrum 399–400
electromagnets 298
electromotive force 270
electrons 31–3
  chemical bonds 35–8
  ions 32–3, 34–5
electrostatic energy 134
electrostatic force 302
electrovalent bonds 36
elements 31
  classification 21, 24–5, 336
  isotopes 40–1, 488
  oxidation number 33–4
  periodic table 24–5, 336
  properties 38–9
embryology 436
embryos 245–7
  cloning 428
  seeds 83
emulsions 106
endemic diseases 176
endocrine system 386–8
endogenous technology 506
endoplasmic reticulum 50
endosperms 83

CamScanner

in rainwater 216, 228
respiration 96, 235, 239
test for 190–1, 441
carbon monoxide 166
carbonates 190–1
carbonation 60
careers 4–5
carnivores 113
carrots 378–9
cassytha 357
cast iron 404
castor oil seeds 84
castration 480
cations 32, 34
cattle 458–61
diseases 466, 467–8
genetic engineering 517
caustic soda 35, 187, 188–9, 218, 507
cell membrane 49, 106, 124–8
cell walls 51
cells
cell division 54–5
energy transformation 134
organisation levels 53–4
structure 49–51
transport systems 124–8
cells (electric) 132, 271
cellulose 51, 105, 108, 117, 128
central nervous system (CNS) 381–2
centre of gravity 307–9
centre of mass 307–8
centrioles 51
centripetal force 306
cereals 67, 375
cerebrum 381–2
cervix 242, 252
CFCs 62, 65, 168–9
change of state 412–16
charcoal 341
cheek cells 53
cheese 515
chemical bonds
see bonds
chemical energy
circuits 270
in photosynthesis 103, 143, 161
respiration 134
chemical industry 192, 344, 346
industrial waste 227, 230
small-scale industries 506–13
chemical weapons 165–6
chemicals
hazardous substances 318–19, 323, 325
solvents 215–16
waste materials 208, 230, 328
chemistry 4, 24–5
chickens
see poultry
child care 249–50
childhood 255–6
Chile saltpetre 188
chitin 105
chlorination 220
chlorine
electronic configuration 33, 37
isotopes 488
molecules 31–2
ozone layer 168
and plants 202
reactions 36, 338, 444
uses 341
chlorophyll 103, 142–3
chloroplasts 50–1
cholera 176, 179, 327, 329
cholesterol 109–10
chromium 340
chromosomes 50, 422–3, 425
in cell division 54–5
inheritance 425–7
sex determination 428–9
chyme 116, 119
circuits 144–9, 270–3, 279–81, 492–5
circular motion 306
circulatory system 261–7
disorders 266–7
circumcision 242–3
cirrhosis 122–3
citric acid 447–8
classification 20–9
cleaning 330–1
climate 64
crops and 367–8
climate change 166–8
clinical thermometers 409
cloning 55, 428, 516
clothing, crops 366
clotting 265
clouds 228, 229, 269, 302
cloven hooves 458
coal
see fossil fuels
cobalt 202, 292, 340, 488
cobalt chloride 214
cochlea 288–9
coconut oil 106, 109, 366, 507, 508, 510–11
coconut shells 346
coelenterates 27
cold blooded vertebrates 27
colostrum 479
colour 399–400
combustion reactions 445–6
communicable diseases 178
communication gadgets 314
communities 151
community hazards 326–7
compasses 294
compost 206–7
compounds 33–5
properties 38–9
concave mirrors 391–2
concentration 42–7
condensation 228, 229, 320, 415
condensation process 104
conduction 403, 405
conductivity 340
conductors 17, 337
semiconductors 133, 136, 145
water 213, 315
cones 339
conglomerates 59
conservation of energy 134, 497
contagious diseases 176
continental drift 172
contraception 258–9
convection 403, 406
convection currents 63
converging lenses 394–5
convex mirrors 391–2
copper
boiling point 413
corrosion 350
properties 404
reactions 338
reactivity 353
uses 340
copper chloride 35
copper sulphate 214
copra 510
corms 89
cornea 395
corolla 77
coronary arteries 261, 266
coronary thrombosis 266
corpus luteum 244
corrosion 191–2, 350–4
corrosive substances 323
couples 301
covalent bonds 36, 215
covalent compounds 36–8
cover cropping 201, 204
cowpea seeds 83–4, 86, 87, 370
cracking 452
creationism 422
crop rotation 204
crop weevil 357–8
crops
genetic engineering 517
harvesting 375–6
nitrogen cycle 67–8
pesticides 4
pests and parasites 357–8, 374–5, 377, 378, 379
production 366–75
radiation 489
vegetable crops 376–9
cross-breeding 456
cross pollination 79

CamScanner

energy *see also* heat; light
circuits 270
conservation 134, 497
efficiency 135
elastic potential 498
electrostatic 134
food chains 161–2
forms of 133–4, 496–8
geothermal 134, 274
interconversion of 497–8
kinetic 134, 496, 497
measurement 10, 17
nuclear 274, 487, 489–91
in photosynthesis 103, 143, 161
potential 133, 496, 497, 498
respiration 134
solar 136–9
sun as 132, 133, 164
thermal 134, 274
tidal 223–4
transformation 134–5
wind 274
entertainment gadgets 314
environment *see also* pollution
industrialisation 166
metal extraction 345–6, 348, 349
urbanisation 332
environmental hazards 319
enzymes
digestive system 50, 115, 117
tooth decay 114
epidermal cells 52, 53, 101, 127
epiphytes 157
epizootic diseases 176
equilibrium 308
esterification 450–1
esters 444, 448–50
estuaries 155
ethane 443, 445
ethanoic acid 188, 448–9
ethanol 408, 413, 446–7
ethene 445, 446
Eustachian tube 288
evaporation 228, 413–14
evolution 433–6
excretion 20, 122, 234–5
excretory organs 235–7
exhalation 98
expansion 410–12
extensive management systems 455, 462–3, 472, 478
eyes 390, 395–7

faeces 67, 117, 122, 234–5, 329, 360–1
Fallopian tubes 242
family planning 258–9
farm animals 454–5
diseases 466, 467–8, 481, 484–5
management systems 455, 457, 462–4, 472–4, 478–9
non-ruminants 469–85
pests and parasites 358–9, 466–8, 480, 484
production 455–8
ruminants 113, 118, 458–61, 467–8
farrowing pens 478–9
fats
diet 109
digestion 119, 122
esters 450
structure and function 106
fatty acids 106, 117, 119–20, 444
esters 450
reactions 447–8
sources of 187, 447
fecundity 456
feedback 281
feeding of animals 457, 464–6, 474–5, 479, 484
fermentation 96, 512, 514–15
ferns 26
ferromagnetic materials 292
fertilisation
in humans 240
in mammals 243–7
in plants 76, 80–1
fertilisers 153, 204–6, 208, 230, 373
fertility, human 251–3
fertility, soil 68, 202–7, 329, 367
fibre 108
fibroids 252–3
filariasis 364
filling-in 372–3
filtration 220–1
fire extinguishers 322
fires 315, 320–3
first aid 315–18
fish 154, 155, 436
fishing 139, 286
fizzy drinks 192
flaccidity 127
flammable substances 7, 318
fleas 467
Fleming, Alexander 6
flight 303–4
flocculation 220
flotation 6–7, 303
flowering plants *see also* photosynthesis
excretion 239
flower structure 76–8
pollination 79–80
transport systems 128–30
vegetative propagation 372
fluoride 115
fluorides 345
focal length 392
food *see also* diet; digestive system
classes of 103–8
contamination 179
crops 366
in plants 103
preservation 489
food additives 121
Food and Agriculture Organization (FAO) 328
food chains 161–2
food poisoning 324–5
food preparation 314
food processing 514
food webs 162–3
foot and mouth 467
forces 10
centre of gravity 307–9
moments 309
and motion 304–7
pressure 309–11
types of 301–3
forests 156–7, 166, 208, 231
formic acid 447–8
fossil fuels 133, 165, 166, 169, 445
fossils 59, 172, 434
fowl 469–77
chick management 471–2
development 436
diseases 476–7
management systems 472–4
production 469–70
fractional distillation 133, 445, 452
fractures 316
free range animals 461, 469, 472
freezing point of water 213
frequency units 10, 270, 285
fresh water ecosystems 154, 156
friction 302–3
advantages/disadvantages 501
in mammals 74
reducing 499–501
fronts 64
fruits 81–3, 85–6
fuels 445–6
petrochemicals 451–3
fumes 320–1
functional groups 443–4
fundamental frequency 287
fungal diseases 177
fungi 27, 28
in food processing 515
fuses 276

Galamsey 347–8
gall bladder 116, 121
gall stones 123
galvanising 352–3
gametes 76, 240
gamma rays 400, 487, 488–9
gas exchange 99–102
gas thermometers 409
gases *see also* atmosphere
change of state 412–13

CamScanner

gases *(continued)*
convection 63–4
diffusion 125
forces in 302
noble gases 35
genes 422–3
genetic disorders 178
genetic engineering 516
genetically modified organisms 517
genetics 426
genotypes 426
genus 24
geothermal energy 134, 274
germanium 145
germination 87–8, 96
gestation period 246
Ghana
metal extraction 344, 346, 349
solar energy 138
water sources 226
Ghana Atomic Energy Commission (GAEC) 490
Ghana Water Company 221
gizzard 119
glands 386–8
glass 404
global warming 62, 65, 166–8
glomerulus 235–6
glucose 104–5
blood glucose levels 122
in digestion 117, 119, 120
in the kidney 236
in the liver 121, 122
in photosynthesis 132, 140
in respiration 94–5, 134
test for 104
glycerol 106, 120, 450, 507
glycogen 105, 120, 121
goats 458, 461
diseases 466, 467–8
gold 337, 353
extraction 346–9
reactions 338
uses 339–40
Golgi bodies 50
gonads 388
Graafian follicles 244, 245, 251
grafting 91
granite 59
graphite 341
grasses 465
grasslands 156, 158, 463
gravity
centre of gravity 307–9
gravitational force 302
gravitational potential energy 498
tides 223
grazing 464–5
grease spot test 106
green manuring 204
greenhouse effect 166–8
grey matter 381
growth and development 20, 253–7
Guinea worm disease 361–2
gutters 330
gynaecium 77

Haber process 340
habitats 150–1
haemoglobin 116, 121, 235, 265, 425, 432
haemophilia 266, 429
hair 105, 237, 238, 256
Hall process 344, 345
halons 168
hard water 191, 216–17
softening 217–19
Harmattan season 226
harmonics 287
harvesting 375–6
hay 465, 466
hazardous substances 318–19, 323, 325
health service organisations 327–8
healthcare 313, 327–32
hearing 288–9 *see also* sound
heart 261–4
disorders 110, 266–7
heartbeat 386
heat
expansion 410–12
latent heat 415
in liver 122
measurement 403–5
nature of 402–3
in respiration 95–6
specific heat 404
transfer 405–7
heat (animal) 244
heat capacity 403–4
hepatic arteries 121
hepatic veins 120
hepatitis 123, 179, 183
herbal medicine 512
herbivores 113, 117
herbs 20
heredity 423, 425–8
heterozygous organisms 426, 428, 431
high blood pressure 110, 266
hobbies 314
hole-in-heart 267
Homo sapiens 504
homologous pairs 426
homologous series 442
homozygous organisms 426
hookworm 364
hormones
destruction of 122
in digestion 116
endocrine system 386–8
in excretion 236
female 242, 256, 259
male 241, 256
production of 105, 106
reproduction 244, 246, 248
horsepower 498
houses
safety 313–15
ventilation 330
wiring 275–6
humans, classification 24
humidity 62, 63, 152, 208
humus 204
hurricanes 64
husbandry 457
hybrids 422, 423, 456
hydration 60
hydraulics 310
hydro-electric power 134, 227, 273, 295
hydrocarbons 442–50
hydrochloric acid 188
digestive system 116, 119
hydrogen
boiling point 413
hydrogenation 225
ionic compounds 36
isotopes 488
pH and 153, 198
test for 190
uses 341
in water 188–9
hydrogen bond 215
hydrological cycle 226–31
hydrolysis 60, 104
hydroxides 35, 187, 199
hydroxyl groups 444, 446
hygiene 176, 329, 361
hypertension 110, 266

ice cream production 512
igneous rocks 58–9
ileum 115
image formation 390–3
immune system 249, 265
immunisation 249–50
Imperial System 9
implantation 244
impotence 253
incisors 112, 113
inclined plane 499
incubation 471
indicators 196–9
indigestion 120, 191
inductors 146, 148
Industrial Revolution 504
industrialisation 166
industries
biotechnology and 514–18
scientific principles 511–13
small-scale 506–11

CamScanner

inertia 305
infancy 255
infectious diseases 176
infertility 251–3
infrared 400
inhalation 98
inheritance 423, 425–8
inorganic acids 187
inorganic compounds 33–5, 440–2
insects 179
insulators 337, 405
insulin 105, 388, 516
integrated circuits 431
Integrated Pest Management (IPM) 375
integrated science 3
intensive systems 455, 463–4, 473, 479
intercostal muscles 98
Intermediate Technology Transfers Units (ITTUs) 505
internal energy 403
international health organisation 327–8
International Red Cross Society 327
intertidal zones 155
invertebrates 27, 160
involuntary actions 384–6
iodine 109
iodised salt 388
ion exchange 218–19
ionic bonds 36, 215
ionic compounds 33, 36
properties 37–8
ions 32–5
iridium 337
iris 396
iron
boiling point 413
properties 337, 404
reactions 338
rust 191–2, 350–4
uses 339
iron sulphide 35
irrigation 208, 373
irritability 20
isotopes 40–1, 488
itches 319
IUPAC 34

jaundice 123
joints 73

kerosene 165, 445, 452
kettle fur 191, 217
kidneys 235–7, 238, 387
kids 461
kilowatts 498
kinetic energy 134, 496, 497
Kingdoms 23, 25–9
kwashiorkor 109

lactose 104, 117, 515
lactose intolerance 109, 120
lagoons 227
Lamarck, Jean Baptiste 433
land breezes 62–3
land clearing 368
land formations 175
landfill 328
large intestine 115, 117, 127
parasites 360–1
latent heat 415
latitudes 63–4
latrines 331
lava 58, 172, 175
layering 91
leaching 67, 202, 204, 208
lead 353
oxidation 350
properties 404
leaves *see also* photosynthesis
cells 52
diffusion 101, 125, 128–9
starch test 140–1
legumes 82
length 10–11
lenses 394–5
lenticels 101–2
lettuce 377–8
leukaemia 266
levers 498
lice 467
life processes 19–20
light
dispersion 397–8
Doppler effect 288
ecosystems 152
electromagnetic spectrum 399–400
formation of images 390–3, 395
in photosynthesis 101, 140, 142
primary colours 399
reflection 389–90
refraction 393–5
light emitting diodes (LEDs) 145, 146, 148
lightning 269, 302
lime
see calcium hydroxide
limestone 59
limewater test 190–1, 441
liming 204
lines of force 296–8
Linnaeus, Carolus 20
lipase 117
lipids 106
liquid petroleum gas (LPG) 452
liquids
change of state 413–16
density 13
diffusion 124–5
expansion and contraction 412
flotation 6–7, 303
forces in 301–2
osmosis 125–8
pressure in 309–10
solvents 215–16
speed of sound 284
lithium 337
litmus 196–8
liver
bile 119
diseases 109, 123
functions 121–3, 235, 265
liver flukes 359
livestock
see farm animals
living things *see also* animals; cells; flowering plants; plants
classification 21–9
ecological concepts 150–1
ecological factors 151–3
ecosystems 153–61
non-living things and 19–20
load 498–500
lodestones 292
logic gates 418–20
lone pairs 37
long sight 397
longitudinal waves 285–6
loudness 287
loudspeakers 295
low blood pressure 266–7
lung cancer 101
lungs
circulation 261–2
problems with 100–1
structure and function 94, 97–100
lymph 117, 264
lysosomes 50

machines 498–500
macro-nutrients 202
magma 58, 175
magnesium 337
compounds 33, 34, 35
in hard water 216, 217, 218, 219
macro-nutrients 202
magnesia 188, 292
molar mass 42
in photosynthesis 203
properties 337
reactions 39, 190, 338
reactivity 353
soil fertility 204, 205
uses 340
magnetic fields 296–8
magnetic force 302
magnetic induction 294
magnetism 292–300, 340
mains electricity 270, 314–15
maize 84, 87, 370, 517

CamScanner

malaria 359–60
malnutrition 109, 250, 258, 464
mammals *see also* humans
  birth 247–8
  circulatory system 261–7
  digestive system 115–19
  fertilisation 243–7
  friction 74
  friction in 74
  reproduction 240–2
  respiratory system 97–101
  skeleton 70–4
  teeth 111
  transport systems 261–7
management systems 455, 457, 462–4, 472–4
mantle 171–2
manures 204
margarine 445
marine ecosystems 154–5
marriage 250, 257
mass 13, 31
  atomic mass 41, 488
  centre of mass 307–8
  mass number 40, 488
  molar mass 42
mass number 40, 488
mating 456
matter 31–3, 412–16
measurement 9–18
mechanical advantage (MA) 498
mechanical energy
  see kinetic energy; potential energy
medicine 516
megawatts 498
meiosis 55
melting 413, 416
membranes 49, 50, 106, 124–8
Mendel, Gregor 423
Mendeleev, Dimitri 21
menopause 259
menstruation 244, 245, 256
mental capacity 257, 425
mental illness 383
mercury 337, 340, 408
mesosphere 165
metabolism 234
metalloids 25, 336
metals
  with acids 190
  classification 25, 336
  conductivity 17, 340
  extraction 344–9
  ions 32
  oxides 187–8
  properties 337–9
  reactivity series 353–4
  uses 339–41
metamorphic rocks 59
meteors 302
methane 443, 444, 445
methanoic acid 448
methyl orange 197–8
metre rule 10
Metric System 9
micro-organisms 49, 176, 234 *see also* bacteria; viruses
  biotechnology 514–18
  metal extraction 347
  soil fertility 204
microchips 431
micrometer screw guage 10
microwaves 400
milk
  for babies 249
  fermentation 514–18
  ice cream production 512
  pasteurisation 512
milk teeth 112
millet 366, 370, 517
minerals
  de-mineralisation 219
  in diet 107–8, 109, 115, 376
  extraction 208
  petroleum 452
  in plants 128–9, 140
  in rock 58, 59, 60, 175
  in soil 19, 202, 208
  in water 45, 227, 229
mining 158, 166, 208, 319, 345, 346, 348
mirages 395, 396
mirrors 390–3
miscarriage 250–1
mistletoe 356–7
mitochondria 50, 51
mitosis 54–5
mixtures 38–9
molar mass 42
molars 112
molecules 31–2
moles (chemistry) 41–2
molluscs 27
mols 42
moments 309
momentum 305, 306–7
monohybrid inheritance 428
monosaccharides 103–4
mosquitoes 359–60
motion 304, 305–7
mouth 115–16
mouth-to-mouth ventilation 317–18
movement 20
mucus 116
mulching 201, 373
multicellular organisms 49
mumps 252
muscle cells 52, 53
muscles 382, 384–6
music 286–8
mutation 425
myopia 397
myxomatosis 485

naptha 452
national grid 275
natural gas 165, 451
natural radioactivity 487–8
natural resources 150
natural selection 425, 433–6
natural system of classification 20, 22–3
neon 341
nerve impulses 106, 289, 384–6, 390
nerves 381, 382, 383, 384–5
nervous system 381–2
neurones 384–5
neutralisation 191–2
esterification and 450–1
neutrons 31, 40
Newton, Isaac 223, 285
Newton's laws of motion 305–7
niches 151
nichrome 342
nickel 172, 292, 299, 337, 340, 411
night blindness 109
nitrate ions 35, 67–8
nitrates 188, 517 *see also* nitrogen cycle
  pollution 166, 169
  trioxonitrate(v) 190, 191
nitrification 68
nitrogen
  boiling point 413
  electronic configuration 33
  fertilisers 153, 204–6, 208, 230, 373
  nitrogen fixation 67–8, 517
nitrogen cycle 67–8
noble gases 35
noble metals 339–40
non-infectious diseases 178
non-living things 19–20
non-metals 336
  classification 25
  ions 33
  properties 337–9
  uses 341
nuclear energy 274, 487, 489–91
nuclear fission 489
nuclear fusion 489
nuclear membrane 50
nuclear waste 490–1
nucleus (atoms) 32–3, 40
nucleus (cells) 50
nuclides 40
numbers 10
nutrition 19 *see also* food
  diseases 178

obesity 110
occupational hazards 319, 320

oesophagus 115, 116
oestrus cycle 244
Ohm's Law 271–2
oil
  see fossil fuels
oils 106, 109, 450, 453
  extraction of 508–11
okro 376–7
old age 257
omnivores 113
onion cells 53
ores 344, 346
organ systems 53–4
organelles 50
organic acids 186–7
organic compounds 442–50
  inorganic compounds and 440–2
ornamental crops 366
osmosis 125–8
osteoporosis 73
ova 244–5
ovarian cysts 253
ovaries 387
  in humans 241–2, 244–5
  in plants 77–8
over-grazing 208
overtones 287
oviducts 242, 244
ovulation 244–5, 246, 252, 256, 259
oxidation 60, 350
oxidation number 33–4
oxides 35
oxoacid salts 35
oxoanions 35
oxygen *see also* respiration; rust
in air 45, 165
  altitude and 153, 424
  boiling point 413
  circulation 261, 262, 265, 266
  electronic configuration 33
  fires 315, 320, 321
  macro-nutrients 202
  non-metals 337–8
  in photosynthesis 140–1, 143, 239
  placenta 246
  uses 341
  water cycle 229
ozone layer 62, 65, 165, 168–9

palm kernel oil 509
palm oil 366, 507, 508–9
pancreatic juice 117, 119, 387, 388
parallel circuits 271
parasites 177
  crops 374–5, 377, 378, 379
  diseases 359–65
  farm animals 358–9, 466–8, 480, 484
  large intestine 360–1
  plants 356–7
parental care 248–50, 257–8
partially permeable membrane 49
particles of matter 31–3
Pascal's principle 310
pasteurisation 512
pathogens 176
pedigrees 455
pendulums 497–8
penicillin 6, 515
penis 241, 242–4, 253, 256
pepsin 116
percussion instruments 283
perennial crops 366
peridontal disease 114
periodic table 21, 24–5
  metals and non-metals 336
peristalsis 116
permanent crops 366
pesticides 4, 153, 230, 374
pests and parasites
  crops 374–5, 377, 378, 379
  farm animals 358–9, 466–8, 480, 484
  plants 356–8
petrochemicals 451–3
petroleum 165, 441, 445, 452–3
pH 198–9
phenotypes 426
phloem 128–30
phosphorus
  animal feed 475
  in diet 108, 115
  fertilisers 205, 377
  ions 33
  nitrogen cycle 67
  plants 140, 202, 203
photosynthesis 103, 140–3
  translocation 129–30
physics 4
pickling 192
pigs 477–82
pitch 286–7
pitfall traps 159
pituitary glands 388
placenta 78, 245–6
plankton 154
plant cells 51–3
  animal cells and 51–4
  organisation levels 53–4
  osmosis and 127
plant nurseries 371–2
planting 367–72
plants
  asexual reproduction 88–91
  classification 20, 21, 26–7, 28
  ecosystem relationships 161–3
  gas exchange 101–2
  growth and development 67, 202–7
  inheritance 427–8
  nitrogen cycle 67–8
  nutrients 202–3
  pests and parasites 356–8
  respiration 101
  sexual reproduction 76–81
  tissue cultures 517–18
  tissues 53–4
  transport systems 128–30
  water cycle 226
plaque 114
plasma 122
plasmolysis 127
plastics 321, 405, 451
plate tectonics 172–5
platelets 265
platinum 340
Plimsoll line 304
plugs 276–7
plutonium 340
pneumonia 101
poisons 178
polar molecules 215–16
pollination 79–80
pollution
  acid rain 65, 169
  air 62, 65
  environmental hazards 319
  genetic engineering 517
  metal extraction 345–6, 348
  nitrates 166, 169
  water 230
polymers 219, 440, 445
polysaccharides 104–5
polythene 440, 441, 445
pomade 512
ponds 151, 154, 368
pooters 159
population pressure 231
populations 151
potassium
  in diet 108, 388
  fertilisers 205, 379
  nitrogen cycle 67
  in plants 203
  reactivity 353
  uses 194
potassium hydroxide 3, 450, 506–7
potential difference 17, 268, 270
potential energy 133, 496, 497, 498
poultry 469–77
  chick management 471–2
  development 436
  diseases 476–7
  management systems 472–4
  production 469–70
power 18, 274, 498
pre-natal care 248–9
precipitation method 192–4, 218
precipitation (weather) 228
pregnancy 245–7
  early parenthood 257–8
  growth and development 253–5
  late delivery 259

pregnancy *(continued)*
pre-natal and post-natal care care 248–9
problems with 250–3
teenage pregnancy 250
premolars 112
pressure 309–11
prisms 398
progesterone 242, 244, 248
prokaryotae 27
propagation 90–1
propane 443, 445
propyl ethanoate 449
prostate gland 238, 241
proteins 105–6
amino acids and 105, 120
in diet 109
digestion 119
digestive system 116, 117, 119
nitrogen cycle 67
plants 140
plasma proteins 122
protoctista 25, 28
proton number 40
protons 31, 188–9
protoplasm 50
protozoa 26, 28
protozoan diseases 177
pruning 373–4
psychotropic drugs 383
puberty 256
public health 327–32
pull 301
pulleys 498–9
pulmonary arteries/veins 261, 262
pulp cavity 111–12
pulse 14
pumps 310–12
pupil 396
pure science 4
push 301
PVC 325, 341
pyorrhoea 114
pyrometers 410

quack doctors 313
quadrats 158–9
quarrying 208
Quorn 515

rabbits 117, 118, 482–5
rabies 176, 177, 178, 179, 183, 481
radiation 325, 406–7
radio waves 400
radioactivity 6, 487–9, 490
radioisotopes 488–9
rain
acid rain 65, 169
air movement 63, 64
carbon dioxide in 216, 228
ecosystems 152
hydrological cycle 226–31
oxidation 60
raindrops 302
rainbows 398
rainforests 156–7
reactivity series 353–4
real images 390
receptors 385
recessive alleles 426, 428, 429, 431, 432
rectum 117–18
recycling 328–9
red blood cells 50, 52, 108, 121, 265
altitude and 424
blood groups 431
breakdown 116, 121, 122
diseases 266, 359, 432
oxygen and 53
red shift 288
reduction 60, 351
reflection 389–93
reflex actions 384–6
refraction 393–5
refuse disposal 328
relative atomic mass 41, 488
relative density 16–17
renal arteries 235
rennin 116
reproduction 20 *see also* sexual reproduction
asexual reproduction 20, 88–91
cell division 54–5
in plants 76–81
unicellular organisms 20, 54
resistance, electrical 10, 17, 271, 272–3
resistivity 278
resistors 145, 146–7, 271–2, 279
respiration 20, 94–6
in cells 50
diseases 178–9
heat energy 95–6
transformation 134
water 228
respiratory system 97–101
resuscitation 317–18
retina 396
rheostats 271
Rhesus factor 431
rhizomes 88
ribonucleic acid (RNA) 51
ribosomes 51
Richter scale 173
rickettsial diseases 177–8
rinderpest 467
ring circuits 276–7
river blindness 364
rivers 60, 154, 209, 226, 227
rocks
characteristics 58–9
radioactive dating 489
weathering 59–60
Roentgen, W 6
roots 101, 128, 129
roughage 108
roundworm 364
rubber 445
rulers 10
ruminants 113, 118, 458–61
diseases 467–8
runners 89–90
rust 191–2
rusting 350–4

sacrificial protection 353
safety
corrosive substances 323
first aid 315–18
hazardous substances 325
in the home 313–15
in the laboratory 7
summary 325
salinity 153
saliva 114, 115, 116, 119
salt production 511–12
salts 35
preparation 192–7
sources of 188, 192
uses 192, 194
sandstone 59
sanitation 178, 314, 329–31
saponification 506
saturated hydrocarbons 444, 450
savannah 158
scalar quantities 14
scalds 316
science 2–5, 503–4
scientific method 5–6
scientific principles, in industry 511–13
sea breezes 62–3
seasons 62–3
seat belts 306
seawater 227
sedimentary rocks 59
sedimentation 220
seedbeds 369–71
seeds
in classification 26
dispersal 85–6
germination 87–8
respiration 96
seed structure 83–5
self-pollination 79
semen 241, 244
semi-intensive systems 463–4, 472–3, 478
semi-metals 336, 337–9, 341
semiconductors 133, 136, 145
series circuits 271

sewage 178, 227, 231, 314, 329–31
sex chromosomes 428–9
sex determination 428–9
sexual intercourse 242, 243
sexual reproduction
  asexual reproduction and 91
  blood and 266
  female reproductive system 241–2
  hormones 248
  inheritance 425–8
  male reproductive system 240–1
  in plants 76–81
  problems with 250–3
sexually transmitted diseases 179, 238, 253–4
shale 59
sheep 458, 461, 466, 467–8
shock 317
shooting stars 302
short sight 397
shrubs 20
sickle cell anaemia 266
sickle-cell anaemia 431–3
silage 465–6
silicon 145
silver 337, 338, 340, 353
single bonds 37
skeletons 70–4
skin 235, 237
skull 71
slag formation 345–6
slaughtering 457–8, 477, 482
sleeping sickness 363–5
small intestine 115, 120, 125
small-scale industries 506–11
smoking 101, 252, 266
soap 216, 450
soap making 506–8
society, technology and 504–5
sodium 338, 340, 353
sodium chloride
  ionic bonds 36
  preparation 195–6
  salt production 511–12
  in seawater 188
  uses 187
sodium hydroxide 35, 187, 188–9, 218, 507
sodium ions 32
soft water 217–19
soil
  conservation 201–2
  depletion of soil resources 207–8
  fertility and productivity 202–7
  formation 58
  nitrogen cycle 67–8
  pH 199
  types of 367
soil erosion 204, 208–10, 224
solar cells 273
solar energy 136–9
solar panels 133, 136–7
solder 342
solenoids 146, 297
solids 412–13, 416
solutes 215–16
solutions 42–7
solvents 215–16
sound 283–4
  amplifiers and reducers 289
  nature of 285–6
  properties 286–8
speed of sound 284–5
specialised cells 52–3
species 20, 23, 24, 150
specific heat 404
spectrum 397–8
speech development 381
speed 14–15, 305
sperm 241, 244
sperm cells 52
spinal cord 381, 383
sprains 316
springs 227, 498
stabilisers 277
stability 308–9
stainless steel 342
staking 373
staple foods 366
starch 105, 140–1
  destarching 142
states of matter 412–16
static electricity 268–9
steel 339, 342
stem cells 428, 516
stem cuttings 90
sties 478
stigmas 78
stomach 116, 119
stomach ulcers 120
stomata 101–2
storms 64–5
stratosphere 165
stress 178
string instruments 283
strokes 110, 266
strong acids and alkalis 199
styles 78
sublimation 416
submerging lands 175
subsistence farming 454
substituents 443
substitution reactions 444
suckers 89
sucrose
  in digestion 117
  in photosynthesis 129, 143
  test for 104
sugars 103–5
sulphide ore 347, 348
sulphur 338
  in diet 105, 108
  in soil 202, 203
  sulphides 32
  uses 341
sulphur dioxide 65, 166, 169, 338, 452
sunlight
  ecosystems 152, 153
  as energy 132, 133, 161, 164
  ozone layer 62, 65, 168–9
  in photosynthesis 101, 103, 140, 142, 143
  radiation 165
  water cycle 226, 228–30
surface tension 215–16
surveyors' tapes 10
sweat glands 235, 237
switches 277
  logic gates 418–20
symbiosis 153
symbols 9–10
synapses 383, 385
syphilis 252, 253
Système International 9–10

technology 3–5
  biotechnology 514–18
  endogenous technology 506
  society and 504–5
teenage pregnancy 250
teeth 111–15
telephones 295
temperature 14, 402–3, 407–8
  ecosystems 151
  thermometers 408–10
terrestrial ecosystems 156–61
testes 241, 387
testosterone 241, 256
tetanus 177, 180, 250, 314
tetraoxosulphate (VI) acid 33, 169, 187, 323, 341
thermal energy 134, 274
thermal equilibrium 402, 403
thermocouples 409–10
thermometers 408–10
thermosphere 165
thermostats 411–12
thinning-out 372
thyroid glands 387, 388
thyroxine 388
ticks 358–9, 467–8
tidal waves 224
tides 223–4
tillage 202, 208, 368–9
timbre 287
time 13
tin 340, 353
tissue cultures 372, 517–18
tissues 53
titanium 340

CamScanner

titration method 194–6
toilets 178, 314, 329–31
tornadoes 64
town planning 331–2
trace elements 202
transformers 274–5
transistors 279–80, 418–20, 431
  combination of 492–5
translocation 129–30
transpiration 128–9, 228
  water 229–30
transport systems
  in cells 124–8
  in mammals 261–7
  in plants 128–30
transportation (vehicles) 165
triatomic molecules 32
triple bonds 37
troposphere 165
trypanosomes 28, 176, 177, 363, 365
trypsin 117
tsetse flies 356, 363–5, 466
tsunamis 174
tuberculosis 101, 176, 178, 179, 181, 481
  immunisation 250
tungsten 337
turgidity 127
twins 246–7
typhoid 180, 230, 329
typhoons 64

ultra-filtration 236
ultrasound 286, 289
ultraviolet radiation 65, 165, 168, 398, 400, 425
umbilical cord 245, 247–8
unicellular organisms 28, 49
  biotechnology 514
  excretion 50, 125, 234
  reproduction 20, 54
  transport systems 124
United Nations 328
units of measurement 9–10
universal indicator 198–9
universal solvent 214
unsaturated hydrocarbons 445, 450
upthrust 303
uranium 6, 341
urbanisation 332, 487
urea 235–6, 237
urinary system 235–7
  disorders 237–9
uterus 242, 244, 247–8
  fibroids 252–3
  miscarriage 250–1

vaccination 327
  farm animals 457, 475
  immunisation 249–50
vacuoles 50
vacuum flasks 407
vagina 242, 243–4, 247
vaporisation 415
vapour 414, 416
variation 423–5, 433
vas deferens 241
vector quantities 14, 301
vectors (diseases) 176, 179, 356
vectors (genetic engineering) 516
vegetable crops 376–9
vegetative propagation 372
veins 262–4
  coronary veins 261
  hepatic veins 120, 121
  pulmonary veins 261, 262
  renal veins 235, 236
velocity 14–15, 305
velocity ratio (VR) 498
vena cava 235, 261, 262
ventilation 330
ventricles 261, 262
venules 262
vernier callipers 10
vertebrae 72–3
vertebrates 22, 27
vibrations 283
video tapes 296
villi 117
viral diseases 177, 182–3
virtual images 390
viruses 29, 176, 177
  diseases 182–3, 253
viscosity 303
vital capacity 99–100
vitamins 106–7, 109, 121
volcanos 174–5
Volta, Count Allesandro 132
voltmeters 296
volume 10, 12
voluntary actions 384

warm blooded vertebrates 27
wars 165–6
washing soda 193, 217, 218, 220
waste materials 208, 230, 328
waste water 231, 328
water
  boiling point 413
  carbon dioxide in 216, 228
  as conductor 213, 315
  conservation 230–1
  contamination 230
  in diet 107–8
  ecosystems 152, 153
  hard water 191, 216–19
  irrigation 373
  minerals in 45, 227, 229
  naturally occurring 212–13, 226–8
  properties 213–15, 404
  purification 219–21
  reactions 338
  respiration 228
  tides 223–4
  transpiration 229–30
  uses 221–2
  water molecules 32, 215–16
water conservation 201–2, 230
water cycle 226, 228–30
water erosion 209
water pollution
  acid rain 65, 169
  diseases 230
  metal extraction 348
water pumps 311
water-related diseases 179, 220, 230
water table 226
water treatment 219–21
water vapour 63
watts 273
wave equation 285
wavelength 285–6
weak acids and alkalis 199
weather 62–5, 228
weathering 59–60
Wegener, Alfred 172
weight 302
wells 228, 231
wet season 152
Wheatstone bridge 272–3
wheel and axle 499
white blood cells 263, 265, 266, 431
whitewash 192
whooping cough 101
Wilson, John Tuzo 172
wind energy 274
wind erosion 209
wind instruments 283
winds 62–5
  ecosystems 152–3
  seed dispersal 85–6
womb
  see uterus
work 497, 498–500
  measurement 10, 17
World Health Organization (WHO) 327–8
worm diseases 361–3, 364, 467
worms 27, 359
wounds 315–16

X chromosome 428–9
X-rays 325, 400
xylem 128–30

Y chromosome 428–9
yeast 266, 324
yeast fermentation 96, 447, 512
yellow fever 29, 177, 183
yoghurt production 514–18

Booklet 2

CamScanner

Ind

Ge	Germanium	Manganese
LR	Lawrecium	Tin
GA	Gallium	Copper Cu
FE	Iron	Rhodium
ZN	Zinc	Caesium
Pb	lead	Xenon
Sc	Scandium	Radium Ra
Mg	Mercury	Nickel Ni
Ti	Titanium	Chromium Cr
Co	Cobalt	Plutonium Pu
		Americium Am

Richard

